Aeroplane Maintenance and Operation Series, Volume 15

INSTRUMENTS

(PART 2)

AEROPLANE MAINTENANCE AND OPERATION SERIES

Compiled under the General Editorship of E. MOLLOY

VOL. NO.

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VOL. NO.

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15 INSTRUMENTS (Part 2)

Dealing with K.B.B. and K.B.B.-Kollsman Instruments, and the operation and maintenance of the Smith's Automatic Pilot.

16 FUEL AND OIL SYSTEMS

Dealing with the maintenance and repair of the Fuel and Oil systems of representative types of Aeroplanes (including Westland "Lysander," Bristol "Blenheim," Pobjoy, and North American), with notes on Testing Aeroplane Fuel.

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INSTRUMENTS

(PART 2)

DEALING WITH K.B.B. AND K.B.B.-KOLLSMAN INSTRUMENTS, AND THE OPERATION OF THE SMITH AUTOMATIC PILOT

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COMPILED BY A PANEL OF EXPERTS

WITH
ONE HUNDRED AND TEN
ILLUSTRATIONS

GEORGE NEWNES LIMITED
Tower House, Southampton Street, Strand
LONDON, W.C.2

equipment renders it of particular value for military operations such as aerial survey and precision bombing.

The master control, or "guiding principle," of the automatic pilot is an air-driven gyroscope. The ingenious manner in which this is utilised to operate the various controls in accordance with the pilot's pre-determined settings is clearly explained in the opening pages of this section. Here again the maintenance engineer is recommended to make himself thoroughly familiar with the principles of operation before attempting the installation and adjustment work which is described in detail in the later pages.

A particularly valuable portion of treatment appears on page 103. It is entitled "Ground Testing, Air Testing, and Fault Tracing," but in order that the reader may be able to take full advantage of these notes, it is essential that he should have thoroughly understood the explanatory notes referred to above.

We take this opportunity of expressing our high appreciation of the generous assistance afforded to us in connection with this section by the makers, Smiths Aircraft Instruments Limited.

Thanks are also due to Messrs. Kelvin, Bottomley & Baird Ltd. and the Kollsman Instrument Company for having assisted us in connection with the sections dealing with their respective instruments.

E. W. K.
E. M.

CONTENTS

INSTRUMENTS

K.B.B. and K.B.B.-KOLLSMAN AEROPLANE INSTRUMENTS

NOTES ON THEIR OPERATION, INSTALLATION, AND MAINTENANCE

AEROPLANE instruments can be divided roughly into two groups, namely:

Flying and navigational instruments, which are necessary to the actual piloting of the aeroplane.

Engine instruments, which give the pilot all the necessary information about the behaviour of the engine.

In the following pages we give details of the operation, installation, and maintenance of the range of instruments for both groups which are made by Messrs. Kelvin, Bottomley, and Baird, Ltd.

SENSITIVE ALTIMETER

This is a high-precision instrument for indicating the altitude at which an aeroplane is flying.

It is based on the well-known "aneroid" principle, according to which an evacuated metal "capsule" expands as the air pressure to which it is subjected decreases with increasing height, and vice versa.

A triple capsule is used in this instrument, which is sufficiently elastic to permit of an axial expansion of some $\frac{3}{8}$ in. for a range of 36,000 ft. (— 1,000 ft. to + 35,000 ft.), and this expansion is amplified through a gear train, carried in jewelled bearings, to give 36 revolutions of the main pointer over a scale of some 9 in. in circumference. This scale, covering 1,000 ft., is subdivided into divisions representing 20 ft., and readings can therefore be easily taken to 5 ft. So sensitive is the capsule of this instrument to the slightest pressure change and so accurately are its movements transferred to the pointers, that changes in height of 5 ft. are readily observable.

A simple temperature compensator acts in direct control of the expansion or contraction of the capsule itself, and, as this compensator is

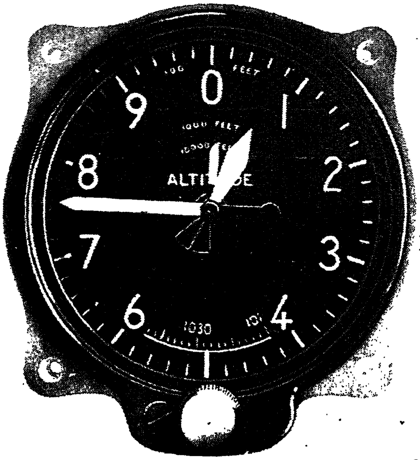


Fig. 1.—SENSITIVE ALTIMETER

adjusted for each instrument individually, errors due to temperature variations anywhere between − 20° C. and + 35° C. are practically negligible.

" Lag " in this instrument is reduced to a minimum, and its readings may be fully relied upon to be accurate to within 1 per cent. of the recorded height, except possibly at heights below 2,000 ft., but, even after a somewhat rapid descent from a considerable height, the error on landing will not normally exceed 20 or 30 ft.

The Pointers

The 20,000-ft. instrument carries two pointers, which are read somewhat like the hands of a clock, the longer making one revolution for 1,000 ft., while the shorter makes one revolution for 10,000 ft. The 35,000-ft. and 50,000-ft. instruments carry a third, still shorter, pointer, one complete revolution of which represents 100,000 ft. In the accompanying illustration the three pointers are reading + 760 ft.

In addition to the main altitude scale, this instrument embodies a subsidiary scale, visible through a " window " in the dial at " six o'clock," which is graduated in actual pressure units, i.e. millibars or inches or millimetres of mercury. This scale is, normally, geared to the pointers, and both can be shifted by rotating the knob at the bottom of the dial. By this adjustment the altimeter can be set to read true height with respect to any ground station at which the prevailing barometric pressure is known. For example, if the subsidiary scale is set to read 1,010 millibars—against the " 5 " graduation on the dial—the instrument will read zero on landing at a station at which the barometric pressure is 1,010 millibars, and will, prior to such landing, read the actual height above that station.

Installation

Installation of the altimeter in the aeroplane is carried out by cutting a hole in the instrument board to take the case and drilling four holes around it for the fixing screws. The Civil-type instrument is inserted from the back of the board and secured thereto with the four screws provided. The Service-type instrument may be mounted with the flange either in front of or behind the board as may be preferred, and is secured with four bolts. As, especially in an enclosed cockpit, the pressure in

the cockpit may vary considerably from the true atmospheric pressure, the nipple at the back of the case is connected by means of a short length of tubing to a branch of the pipe line leading from the "static" tube of the pitot head to the air-speed indicator, care being taken that this connection is completely airtight.

Maintenance

Owing to the various parts of the movement, delicate in themselves, being firmly mounted in a single, rigid casting—the "mechanism body"—this instrument is thoroughly robust, and is therefore likely to require very little in the way of maintenance attention, even after long periods of use.

Checking Case for Airtightness

It is, however, vital to the accurate functioning of this instrument that the case should be practically airtight. This should therefore be checked from time to time, which may easily be done as follows, probably without removing the instrument from the dashboard: detach the connection between the nipple at the back of the instrument and the "static" pipe line, and attach a short length—say 18 in. to 2 ft.—of rubber tubing to the nipple. Gently apply suction (*not* pressure) to the instrument through this tube until it reads, say, 4,000 ft. On closing the tube by a clip or by bending it back on itself and pinching it, the pointer, after an initial immediate drop of 10–20 ft., should not recede more than 150 ft. in one minute (for Service instruments, 50 ft. in one minute

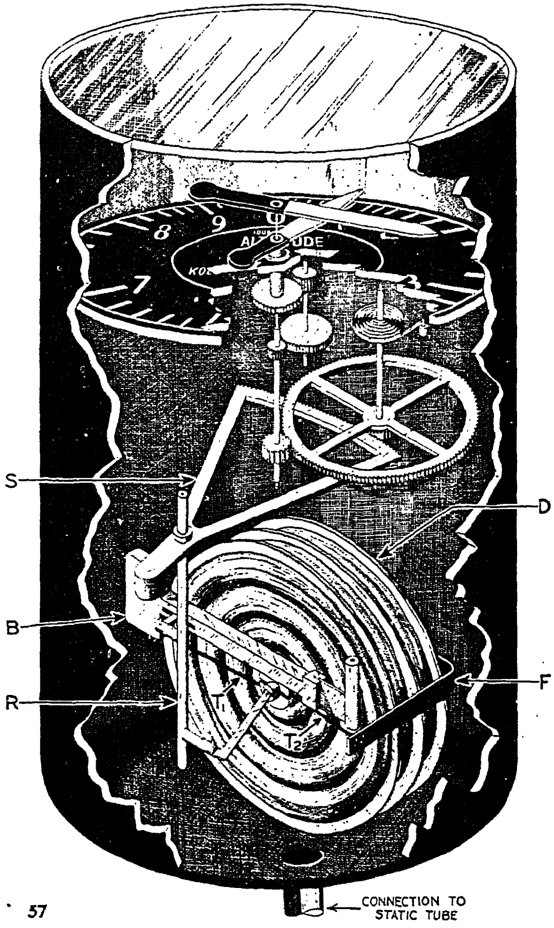


Fig. 2.—DIAGRAMMATIC VIEW OF MAIN MECHANISM OF SENSITIVE ALTIMETER

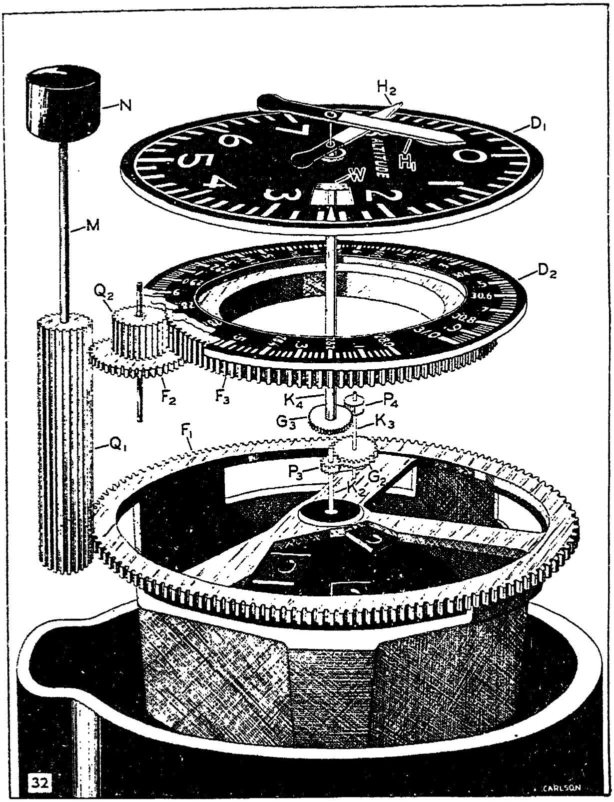


Fig. 3.—DIAGRAMMATIC VIEW OF BAROMETRIC SCALE MECHANISM OF SENSITIVE ALTIMETER

from 1,000 ft.). Should this amount be exceeded, the test should be repeated, and, if leakage is confirmed, the instrument should be removed from the dashboard.

Where to look for Leaks

Apart from a crack in the case, which is quite unlikely unless the instrument has received a blow or some severe jar, a leak is most likely to have developed at the static nipple or round the glass. The nipple may be carefully screwed out from its socket, its threads very lightly smeared with shellac varnish or bakelite varnish and then screwed back while the varnish is still tacky. It will be noticed that this is a tapered thread, so no great force is needed or should be used in screwing the nipple back.

The Snap Ring

The leak test should then be repeated, and if a leak is still indicated, it must now be suspected of occurring round the glass. Such a leak will almost certainly be due, either to failure of the outer " snap ring " to keep the glass firmly pressed down on to the rubber sealing ring under the glass, or to a fault in this rubber ring itself. The snap ring will be found round the periphery of the glass in contact with its outer surface. This ring should be pressing tightly against the glass and into the slight recess in the wall of the case, which is provided to keep it in place. If it is not, and if it cannot be " snapped " back into position with no trace of slackness, it should be replaced.

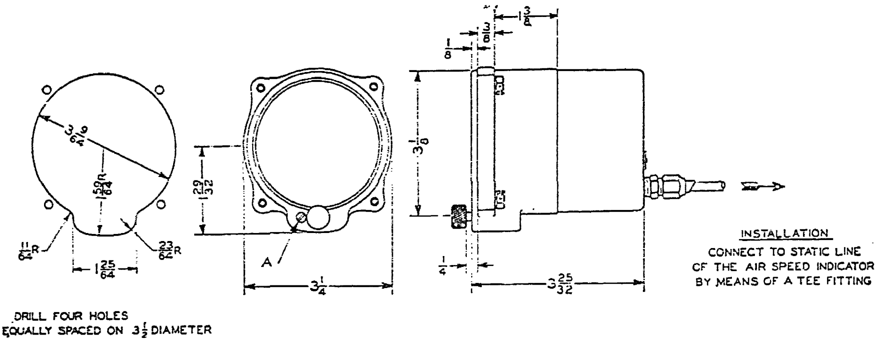


Fig. 4.—INSTALLATION DIAGRAM FOR SENSITIVE ALTIMETER

Fixing holes for Civil type, 0·169 in.; for Service type, 0·206 in.

The Rubber Sealing Ring

If, however, this ring is tightly in place and the case is still leaky, attention to the rubber sealing ring is indicated. To gain access to this, the outer snap ring and glass must be removed. The ring may easily be forced out by inserting a knife blade or small screwdriver between it and the glass close to where its ends meet, and the glass may then be lifted out by means of a suction cup. Should this latter not be available, the glass may usually be removed with the aid of a small piece of plasticine or putty, especially if the case be inverted and the glass withdrawn downwards.

Immediately below the glass will be found the rubber sealing ring housed in a U-shaped channel formed by the inner wall of the case and the ┘-shaped retaining ring. These may conveniently be removed together, but in replacing the sealing ring, the retaining ring must be put back in position in the case first, and a strip of the proper rectangular section rubber specially provided for the purpose worked into the channel between this ring and the case.

This strip of rubber must in no circumstances be put into the channel with any stretch; it should, on the contrary, be literally "stuffed" into the channel as tightly as possible without bulging and the ends made to butt together without any gap. The glass may now be replaced and the resealing of the case completed by pressing the outer snap ring back into position, making sure that it is properly entered into the recess in the case and is in close contact with the glass.

A leak may also occasionally develop round the shaft of the adjusting knob, though this is unusual. Should leakage at this point be suspected, the instrument should be sent to a properly equipped instrument repair shop, as rectification involves partial dismantling.

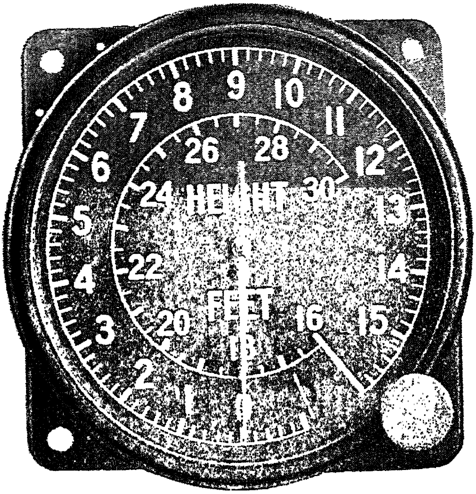


Fig. 5.—Simple altimeter, Service type

Checking Shift of the Pointers

The release of internal stresses in the diaphragm may result in a slight zero shift of the pointers after the instrument has been in use for some time. This should therefore be checked periodically, say, every three months, any shift which has taken place being indicated by the fact that the pointers do not read exactly zero when the barometric scale is set to the true barometric pressure actually obtaining at the moment.

Any discrepancy should be rectified as follows: set the pointers to zero and then loosen the zero setting screw, which will be found just to the left of the adjusting knob. When loosened, this screw can be shifted to the left and the adjusting knob pulled outwards, in which position rotating it will move the barometric scale without moving the pointers. The scale should now be adjusted to read the true barometric pressure, the knob pushed back, and the zero setting screw slid back into place and screwed home. In the Service-type and in some Civil-type instruments the zero setting screw is found on the underside of the barometric scale-setting gear housing, immediately below the adjusting knob, and does not require shifting to the left after being loosened.

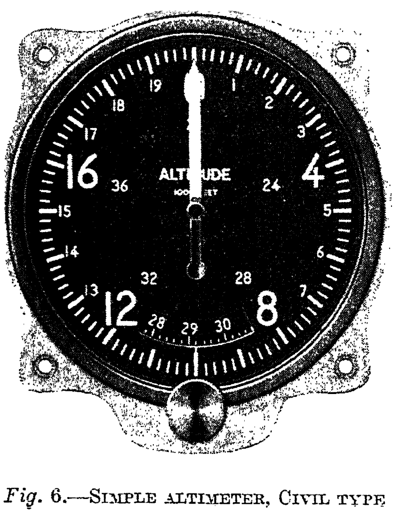


Fig. 6.—Simple altimeter, Civil type

Static Pipe Line

The only other respect in which servicing attention is normally required for this instrument is in keeping the static pipe line free from water and foreign matter. This is done by disconnecting the static pipe line from the nipple of the altimeter and blowing through the line. This pipe line, of course, also serves the airspeed indicator and

the rate of climb indicator, if present, so it is *highly important* that all instruments should be disconnected from the pipe line before it is blown through.

Details of the instrument board cut-out, etc., for installation purposes, are given in the accompanying sketch.

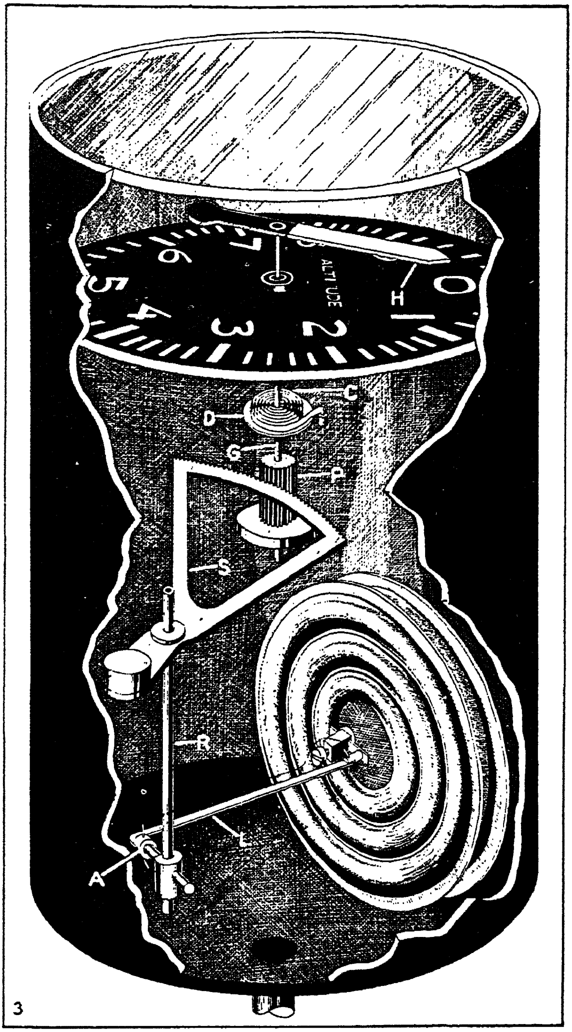


Fig. 7.—DIAGRAMMATIC INSIDE VIEW OF SIMPLE ALTIMETER

SIMPLE ALTIMETER

This instrument is similar in principle to the sensitive altimeter, but is of a somewhat simplified design and is not intended to function to the same high standard of accuracy as the latter. It carries one pointer only, which makes $1\frac{1}{2}$ or 2 revolutions, according to type and range, in covering the full range of the instrument. This implies a much less open scale, and the instrument is not intended to be read closer than some 50 ft.

Two types are produced, one intended for civil use only, and the other the Service " Mk. XIII " pattern, of which a replica is also available for civil use. In the Civil-type instrument, a fixed barometric scale is visible through a " window " in the dial at " six o'clock," and the dial is rotatable by means of the adjustment knob with respect to this scale and the pointer. This scale is read against an elongated graduation mark on the dial diametrically opposite the " 0," and this instrument

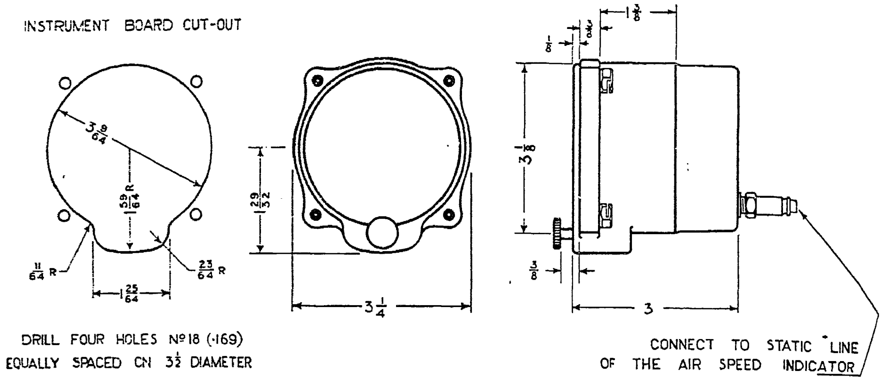


Fig. 8.—INSTALLATION DIAGRAM FOR SIMPLE ALTIMETER, CIVIL TYPE

will read zero when subjected to the actual atmospheric pressure indicated on the barometric scale.

In the Service-type instrument the dial is also rotatable with respect to the pointer and also to a fixed " lubber line " visible through a small aperture in the dial about 20° counter-clockwise from the " 0 " graduation. With the dial set to this lubber line, the instrument will read height in feet corresponding to the actual barometric pressure to which it is subjected.

It should be noted that the Civil-type instrument is calibrated to the I.C.A.N. Law and the Service- (Mk. XIII) type instrument normally to the Isothermal Law.

The Civil-type instrument complies with A.R.B. Civil Specification No. 1A, and the Service-type with Civil Specification No. 1 and with the Air Ministry's (D.T.D.) Specification for the Mk. XIII altimeter.

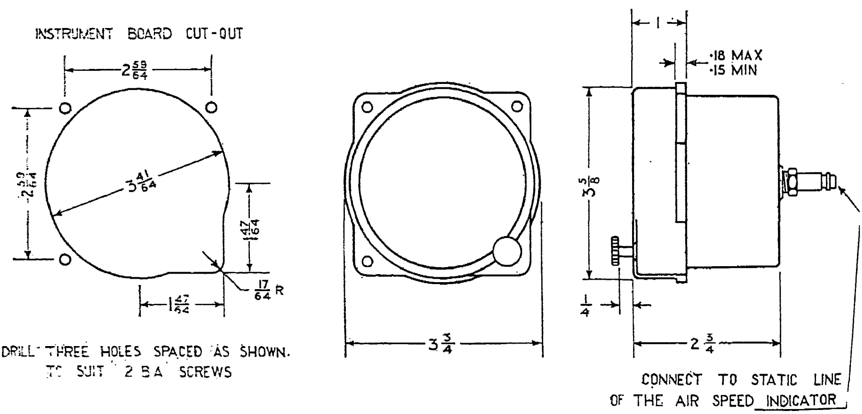


Fig. 9.—INSTALLATION DIAGRAM FOR SIMPLE ALTIMETER, SERVICE TYPE

Maintenance

Maintenance of this instrument is exactly as described for the sensitive altimeter, except that no provision is made for adjusting "zero shift," as any error that may possibly arise from this cause in this instrument is so slight as to be negligible. Should any serious zero error appear at any time, this can only be due to other causes, and the instrument should be sent either to the makers or to a properly equipped instrument repair shop for attention.

Installation is carried out exactly as described for the sensitive altimeter. Details of instrument board, cut-out, etc., for the two types are as shown in the accompanying sketches.

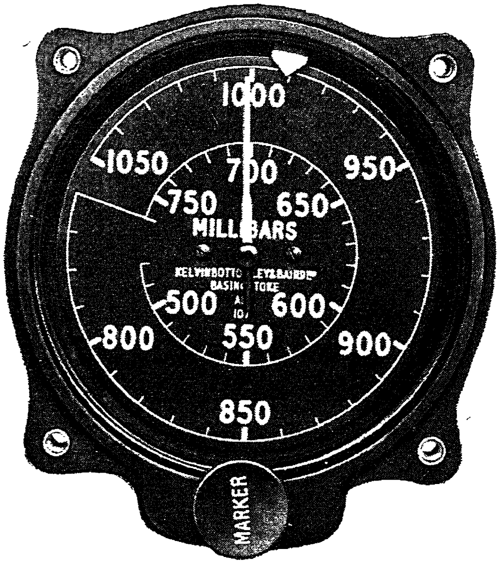


Fig. 10.—Absolute (atmospheric) pressure indicator

ABSOLUTE (ATMOSPHERIC) PRESSURE INDICATOR

This is a modification of the ordinary altimeter for use when an aeroplane is flying in a "controlled zone." It is an increasing practice, in the case of landing grounds which are in radio communication with departing or approaching aeroplanes, to require these aeroplanes to fly

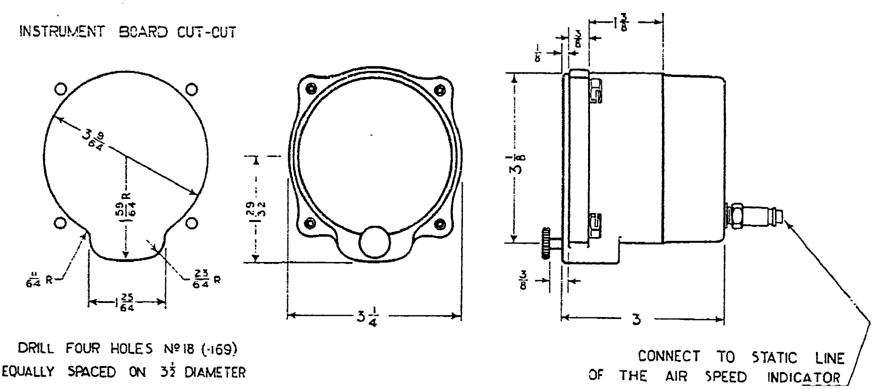


Fig. 11.—Installation diagram for absolute (atmospheric) pressure indicator, Civil type

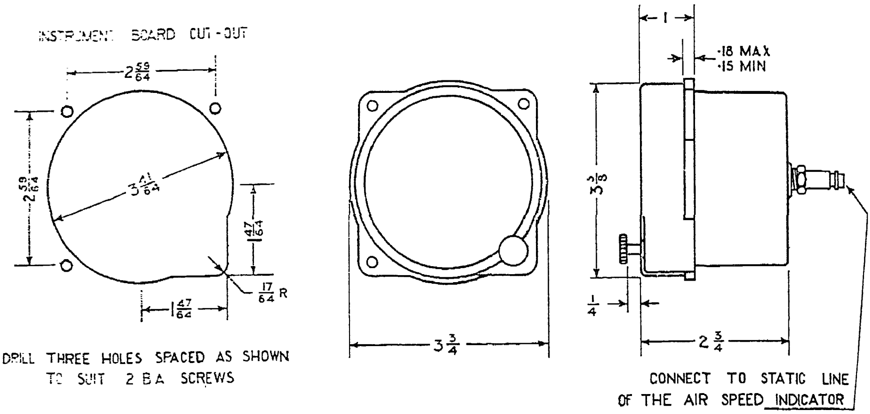


Fig. 12.—Installation diagram for absolute (atmospheric) pressure indicator, Service type

in specified "pressure lanes" rather than at specified heights as such. This instrument is designed to meet the Air Registration Board's requirements for this purpose and complies with Civil Specification No. 20.

To meet this special purpose, it is calibrated in absolute pressure units, i.e. millibars, and the dial is scaled for a range of 1,050 to 480 millibars. A feature of this instrument is the open scale over which the pointer makes (approximately) two revolutions for this range. This gives about $\frac{1}{4}$ in. on the scale for 10 millibars, and readings may therefore easily be made to 2 millibars.

In all general respects, both in design and construction, this instrument corresponds closely with the sensitive altimeter, except that there is, of course, no means of adjusting it in respect of the prevailing barometric pressure, as it is specially intended to facilitate flying at a predetermined pressure level, irrespective of the actual barometric pressure. To this end an adjustable marker rides against the outer scale, and can be set to any desired reading by means of the knob at the bottom of the dial. This marker having been set to the desired reading, the pilot has only to maintain coincidence of the pointer with it to ensure that he is flying in the required "pressure lane."

Two types of this instrument are in use, but they are identical in all respects except for the size and details of the case.

Maintenance

Maintenance is carried out in the same way as for the ordinary altimeters, and in this case, as with the simple altimeter, attention is not required to "zero shift." For the leak test for this instrument suction should be applied to the nipple till the pointer reads 900 millibars, and, on closing the tube, this reading should not drop more than 5 millibars in 1 minute.

The method of installation is exactly as already described for the simple altimeter, and details of the instrument-board cut-out, etc., for the two types are given in the accompanying sketches.

RATE OF CLIMB INDICATOR

The K.B.B.-Kollsman rate of climb indicator operates on the well-known principle of indicating the pressure differential between a chamber in which the pressure is always that of the surrounding atmosphere and changes instantaneously with that pressure during climb or descent and an airtight chamber which only relatively slowly assumes atmospheric pressure through a small leak.

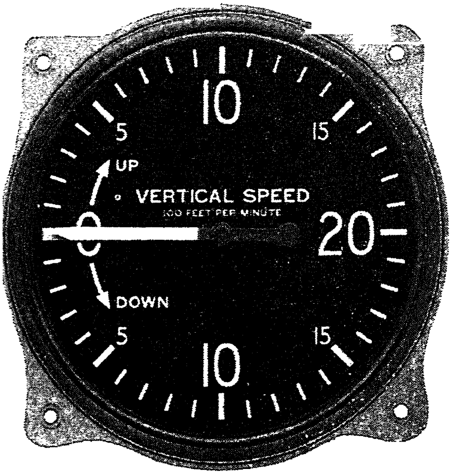


Fig. 13.—RATE OF CLIMB (VERTICAL SPEED) INDICATOR

In this instrument this principle is applied by making the whole of the airtight case the slow-changing pressure chamber, and placing within it a highly sensitive flexible metal capsule, the interior of which is directly connected to the outer atmosphere. As a detail of the design, for simplification of construction, a tube leading to the inside of the capsule and the fine capillary constituting the leak to the case are both taken to a common duct passing through the rear wall of the case to a nipple which is connected to the static pipe line.

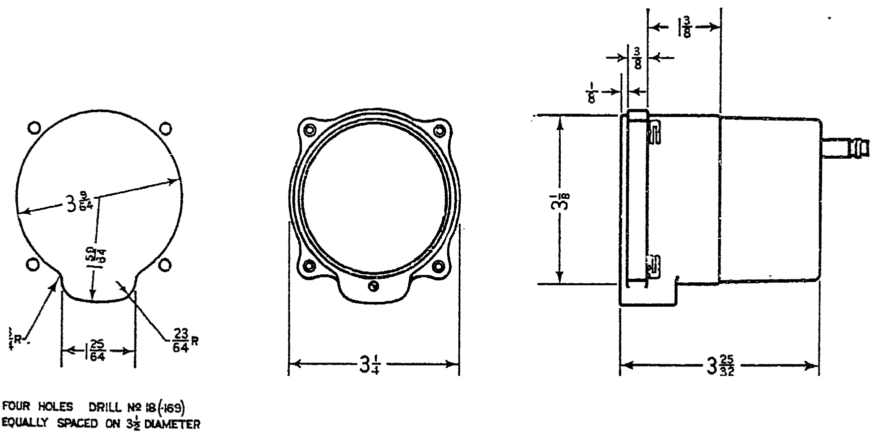


Fig. 14.—INSTALLATION DIAGRAM FOR RATE OF CLIMB INDICATOR, CIVIL TYPE

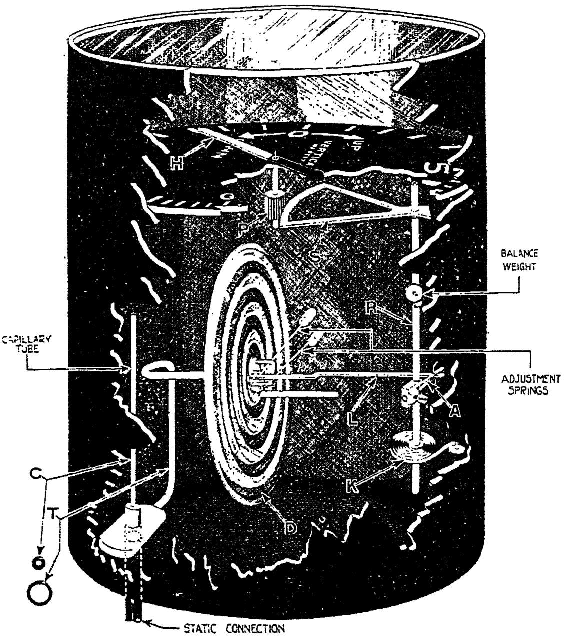


Fig. 15.—Diagrammatic inside view of rate of climb indicator

A pressure differential is thus set up between the capsule and the case corresponding to the changes of atmospheric pressure when the aeroplane is climbing or descending as the case may be. The resulting contraction or expansion of the capsule is amplified and transferred to a pointer through accurate gearing, and this pointer moves over a scale which gives a direct reading of the actual rate of climb or descent. This scale is graduated in either feet per minute or metres per second. In the zero position the pointer is horizontal and pointing to the left. For climb it moves upwards, clockwise, and for descent downwards, counter-clockwise, thus distinguishing easily between the two directions.

Highly efficient compensation for both altitude and temperature is incorporated in the design of the leak itself, and errors due to either of these are practically negligible for any conditions likely to be encountered during flight.

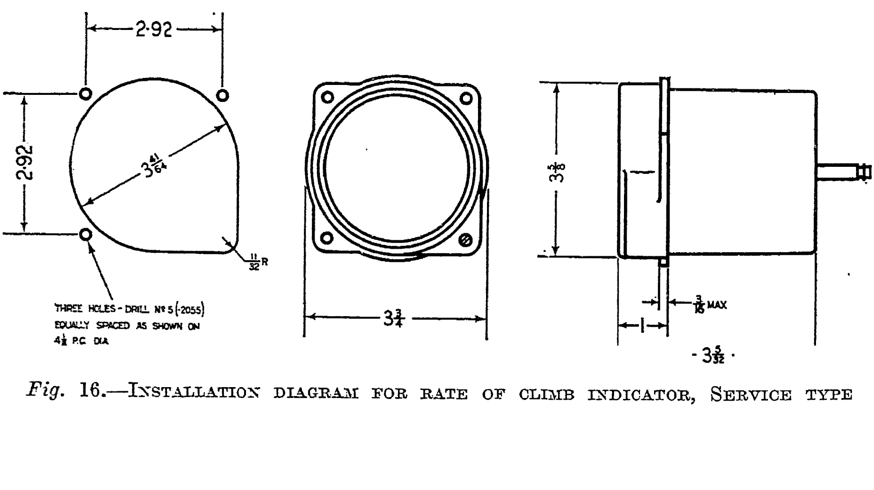


Fig. 16.—Installation diagram for rate of climb indicator, Service type

The range of the instrument is either 0–2,000 ft. per minute or 0–4,000 ft. per minute (metric, 0–10 or 0–20 metres per second), and the scale is sufficiently open to permit of readings being taken by the pilot to some 25 ft. per minute in the former case and 50 ft. per minute in the latter. Some instruments with a range 0–2,000 ft. per minute have a scale specially open from 0–500 ft. per minute.

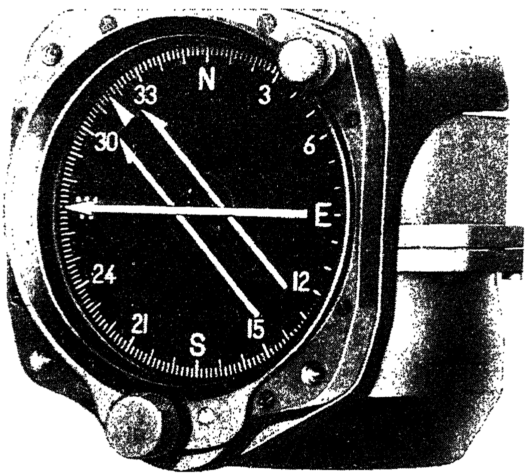


Fig. 17.—Direction indicator

Maintenance

The only maintenance attention required for this instrument is to see that the case remains airtight, and that the "static" pipe line is free from water and/or foreign matter. The latter point has already been dealt with in connection with altimeters.

Any leak in the case will be indicated by the instrument failing to read zero during level flight, and, should this be noticed, attention may well first be given to the nipple, exactly as already described for altimeters. Should this not succeed in curing the leak, the instrument must be removed from the dashboard and sent for attention to a properly equipped instrument test or repair shop, as the carrying out of a definite leak test requires special apparatus.

Adjusting Position of Pointer

In spite of the high degree of precision in its mechanism, this instrument is thoroughly robust, and will stand the strain of "power diving" up to 25,000 ft. per minute or even more without damage or interference with its accuracy of calibration. All rate of climb indicators based on the "leak" principle, however, have a tendency for the pointer to come to rest slightly "off zero," and the position of the pointer should be checked before take off. If required, adjustment can easily be carried out by means of the zero adjusting screw, which will be found just below the dial, either in the middle or at the right-hand corner. If the engine is not running, the instrument should be lightly tapped while making this adjustment. In adjusting the zero with the instrument removed from the aeroplane, it should be held by the flange only, as warming the body of the case by holding it in the hand will expand the air in the case

and set up a slight pressure differential, thus causing the pointer to move slightly.

Installation of the rate of climb indicator is carried out exactly as already described for altimeters. Details for the cut-out in the instrument board, etc., are given for both types in the accompanying sketches.

It should be specially noted that it is imperative that this instrument be detached or completely blanked off from the static pipe line to the pitot head when testing the pipe line for airtightness as well as when clearing it of water or foreign matter.

DIRECTION INDICATOR

This is a modification of the ordinary compass intended for the special purpose of facilitating the pilot of an aeroplane in course-keeping with the minimum of attention. It is not intended to replace the standard type of compass for strictly navigating purposes, as such.

The instrument is based on the regular type of compass, with a liquid-filled bowl and multiple magnetic element, but the deflections of this element, instead of actuating a rotating " card " in the usual way, are transferred through a special magnetic coupling and highly accurate and friction-free gearing to a pointer which rotates in front of a dial in a plane at right angles to that of the compass unit itself.

This permits of the instrument being made up to correspond with the usual type of dashboard instrument and to be mounted on the dashboard with the dial vertical. The dial is fixed and the N.S.E.W. points are marked, N. being at the top. It is graduated from 0° to 360° in 2° divisions, and thus corresponds exactly with the " compass rose " as printed on all aeroplane charts. The indicating pointer, actuated by the magnetic element, rotates freely in front of the dial and constantly shows the

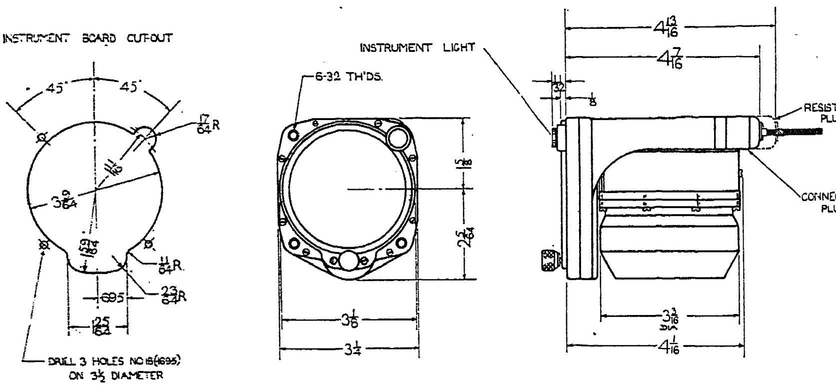


Fig. 18.—Installation diagram for direction indicator

"heading" of the aeroplane. In the accompanying illustration, a heading of 270° is indicated.

In addition, a reference index is also rotatable in front of the dial between it and the pointer, and can be set to any desired reading by means of a knob at the bottom of the dial. If this index is set to the required heading, the pilot can keep his aeroplane on the desired course by merely an occasional glance to see that the indicating pointer remains parallel to the reference index lines. By this arrangement parallax is also eliminated, and accurate observation of the course as shown by the instrument may be made from a considerable angle.

As this instrument is normally fitted with a special form of glare-free rim lighting, the case is made up to accommodate this, but it may be omitted without in any way interfering with the satisfactory performance of the instrument, of which the pointer, reference index, and principal points are luminised in any case.

Maintenance

In spite of its precision, this instrument is so robustly constructed as to withstand all the conditions of service for a prolonged period without requiring attention.

Maintenance, as such, is not therefore required, and should it become apparent that the instrument is not functioning correctly and does require attention, this *must* only be given by skilled compass repairers and adjusters in a properly equipped shop. A rattling sound when the instrument is shaken is not an indication of any fault, provided the pointer is moving freely and indicating correctly. It is due to the special provision made to accommodate expansion and contraction of the liquid with which the compass bowl is filled.

Installation

Installation is carried out as for any typical dashboard instrument, and details of the dashboard cut-out, etc., are given in the accompanying sketch.

When installing, attention should be given to possible magnetic interference in the aeroplane itself. A special compensator for dealing with this is incorporated in the instrument, and the necessary adjustment may be quickly and easily made by turning the slotted heads marked "N.-S." and "E.-W.," on either side of the index setting knob, by means of a non-magnetic screwdriver.

ACCELEROMETER

This instrument has not yet become an item of standard equipment in most aeroplanes. It is in use, however, in an increasingly large number of training aeroplanes and civil passenger-carrying aeroplanes, so a description of it may well be included in this series.

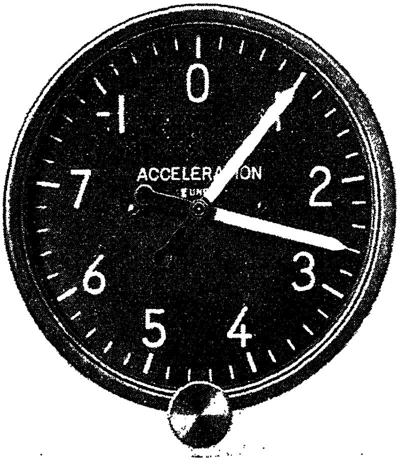


Fig. 19.—Accelerometer

This instrument has been designed for indicating the stresses due to acceleration to which an aeroplane is subjected during flight and especially during landing and take-off. These stresses are indicated in g units. The mechanism is so designed and arranged that the reaction to kinetic forces due to acceleration along axes other than the vertical causes no movement of the pointer. Indications are thus caused only by acceleration along the vertical (Z) axis.

The instrument is of exceptionally sturdy construction, so that there is no need for the mechanism to be locked during transit. This sturdiness, combined with its compact size, permits of this instrument being permanently installed on the instrument board of an aeroplane if so desired.

In addition to the main pointer, which indicates continuously, a second pointer acts as a "tell-tale," and remains at the maximum value until reset. This resetting is achieved by a slight clockwise rotation of the knob at the bottom of the dial, which releases the maximum indicator and permits it to rejoin the other pointer. In one model this release is operated by a separate loose key, so that the maximum indication will remain set and undisturbed until this key is available for resetting, as this may be a desideratum on training aeroplanes. The knob-type instrument may, of course, be reset at any time, and the instrument may thus be used for obtaining a series of determinations of maximum stresses experienced during a series of evolutions, including take-off and landing, without the necessity of the pilot keeping the instrument constantly under observation.

Maintenance

As already intimated, this instrument is sufficiently robust as to be very unlikely to require servicing attention. A broken glass may easily be replaced by removing the snap ring. Any further repairs should only be undertaken where both experienced personnel and the special apparatus required for recalibration are available. Installation on the dashboard is carried out in the ordinary way, and the details of dashboard cut-out, etc., are identical with those already given for the simple altimeter.

K.B.B.-KOLLSMAN ELECTRICALLY HEATED PITOT-STATIC HEAD

Fig. 20.—Pitot-static head, horizontal mounting

This electrically heated pitot-static head probably represents the most successful effort which has yet been made adequately to protect this vitally important component from icing without interfering with its aerodynamic accuracy for the indication of air speed.

This has been achieved by assembling the pitot and static tubes in a one-piece nickelled-copper casing of correct aerodynamic shape, which also contains the heating elements. The pitot opening is in the centre of the forward end of this casing and the static opening is provided by slots or rows of small holes farther back in the casing. Entry of water into the tube proper is prevented, firstly, by a baffle near the opening, and secondly, by a trap and drain farther back.

The special electrical heating elements are hermetically sealed into the casing and cannot possibly come into contact with moisture. They are so placed as to give maximum heating effect at the points where ice is most likely to form, especially the nose, and the high conductivity of the copper casing ensures thoroughly effective heat distribution throughout the head.

The resistance of these elements varies with temperature, and automatically regulates the current consumption according to the conditions to which the head is exposed, thus completely protecting the elements from being burned out should the current be left switched on. This permits of the electrical connections between heating elements and con-

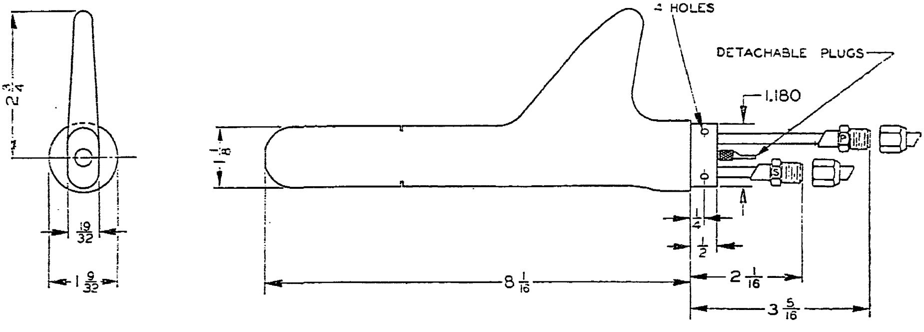


Fig. 21.—Installation diagram for horizontally mounted pitot-static head

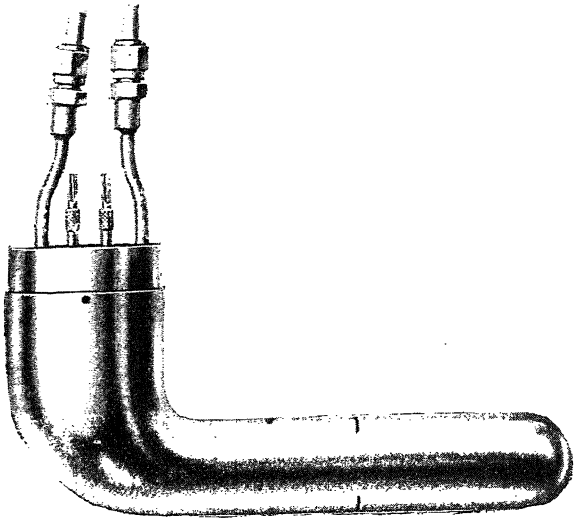


Fig. 22.—Pitot-static head, underwing mounting

necting leads welded and enclosed in permanent sheaths, thus eliminating all risk of contacts becoming loose.

Maintenance

The robust construction of this pitot head and the thorough protection of the heating elements from deterioration or injury ensure that it will give satisfactory performance over a long period of use unless actually damaged. Maintenance attention is therefore unnecessary, but should a damaged head require repair, this can only be carried out by the makers.

Installation

Three types of this head are made, intended for horizontal, underwing, and overwing mounting respectively, and the method of installation

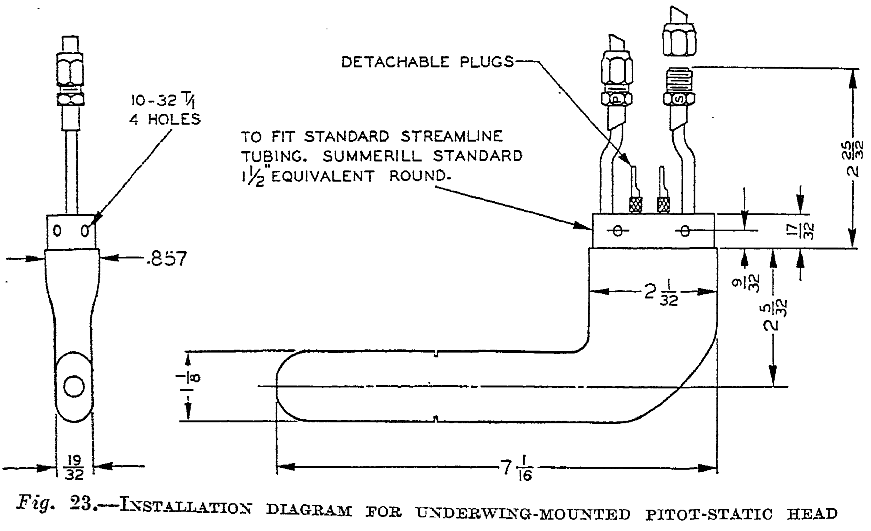


Fig. 23.—Installation diagram for underwing-mounted pitot-static head

requires no description, as it will at once be obvious from examination of the head itself. Details of essential dimensions, etc., for mounting are given in the accompanying sketches.

A special feature of this pitot head in contrast with certain other types is that the pitot tube and the static tube are drained quite separately from each other. This permits of testing the pitot line and the static line separately for airtightness without dismounting the head from the aeroplane, which cannot be done when the pitot and static tubes both drain into a common outlet.

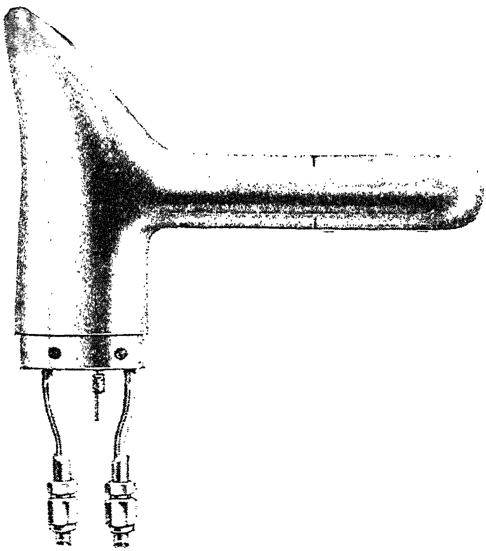


Fig. 24.—Pitot-static head, overwing mounting

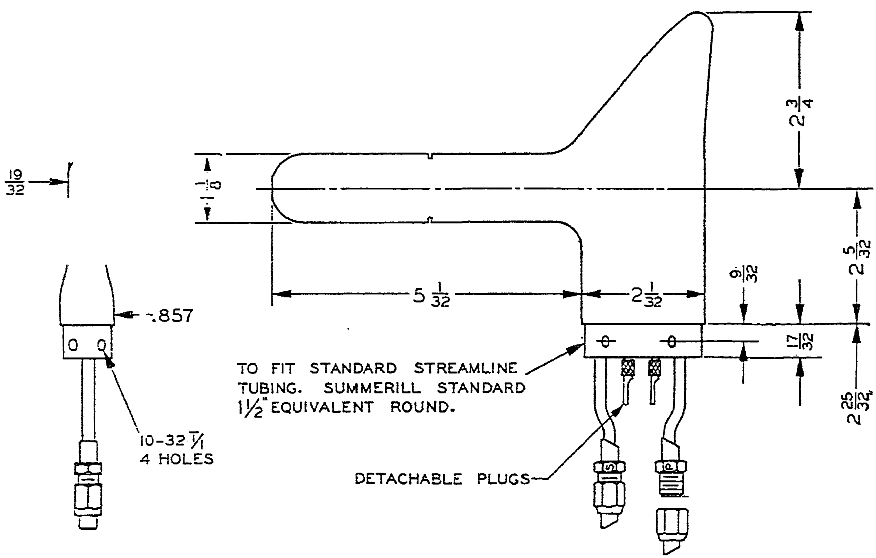


Fig. 25.—Installation diagram for overwing-mounted pitot-static head

It should be specially noted that many of these heads have two separate drain holes for the pitot tube, one just below and behind the opening in the nose and the other near the opposite end. Both must, of course, be blocked when testing the pitot line for airtightness with the head installed.

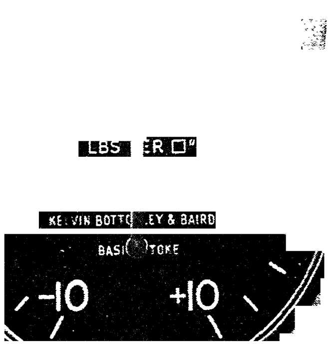


Fig. 26.—Boost gauge

BOOST GAUGE

This consists essentially of a sensitive and accurate pressure gauge, reading absolute pressure in lb. per square inch, millimetres of mercury, or other suitable units.

It has, however, a unique feature in the pressure-sensitive capsule or "cartridge." This consists of a cylindrical metal box of relatively large size, rigid except for one end, which is a flexible metallic diaphragm. This cartridge is hermetically sealed and evacuated, and inside it is assembled the whole of the precision linkage and gearing by means of which the movement of the diaphragm is amplified and converted into rotative effect on a shaft mounted axially in the cartridge. At the end of this shaft remote from the diaphragm and just inside the rigid end of the cartridge is mounted one half of a magnetic coupling. Facing and concentric with this, outside the cartridge, in the space between the cartridge and the dial, is mounted the other half of the magnetic coupling, and from this a short shaft extends through the dial and carries the pointer.

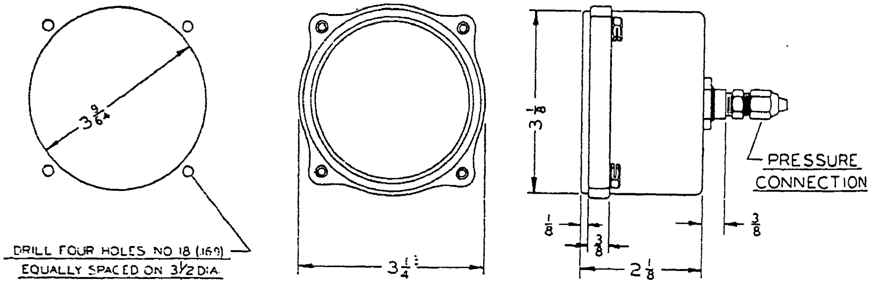


Fig. 27.—Installation diagram for boost gauge

A nipple at the back of the case connects the interior of the case proper with the inlet manifold, but the whole of the mechanism, being housed inside the sealed cartridge, is protected from contact with the manifold gases with their inevitable content of fuel vapour and dirt. The cartridge is so mounted in the case as to protect the dial and pointer also from these gases, and deterioration of the luminous compound with which these are treated is thus also prevented.

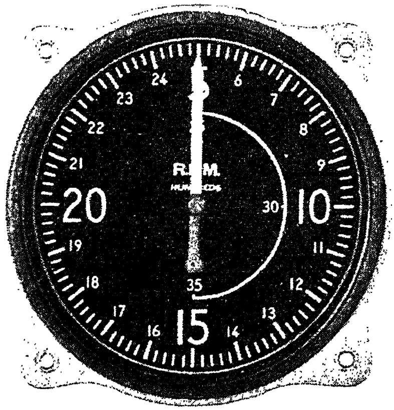


Fig. 28.—Engine-speed indicator (magnetic or electrical)

Protection of the mechanism in this way and its robust construction, together with the free and practically frictionless movement of the magnetic coupling, assured by both shafts being carried in cup-shaped end jewels, ensure long and accurate functioning for this instrument.

By virtue of the arrangement described, the instrument case does not need to be pressure-tight, and the danger of over-supercharging the engine due to a leak in the gauge is eliminated.

Maintenance

A highly important outcome of the unique design of this instrument is that maintenance servicing, with the possible exception of the replacement of a broken glass, is practically eliminated. It is fully temperature compensated, and is extremely unlikely to develop errors even after long periods of service. Should attention to the instrument be required, this

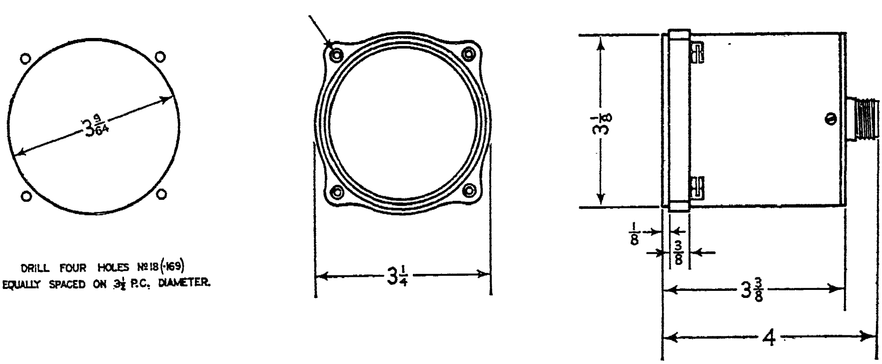


Fig. 29.—Installation diagram for magnetic engine-speed indicator

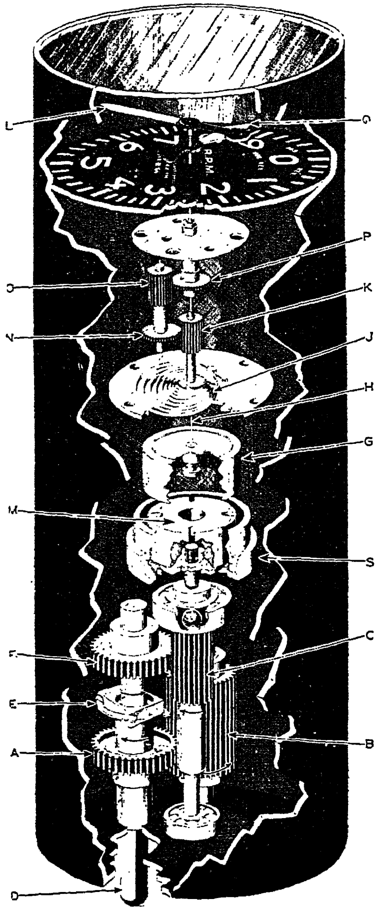


Fig. 30.—Diagrammatic inside view of magnetic engine-speed indicator.

must be given in a properly equipped repair shop, as it is bound to involve recalibration. Repair to the mechanism inside the cartridge should not be attempted. A damaged or suspected cartridge may be completely replaced without any difficulty and the instrument recalibrated, but the removed cartridge should be sent to the makers for any attention it may require.

Installation is carried out in the normal manner, and involves, of course, connecting the nipple at the back of the case with the engine-inlet manifold by means of copper tubing or the like. Details of the dashboard cut-out, etc., are given in the accompanying sketch.

MAGNETIC ENGINE-SPEED INDICATOR OR TACHOMETER

This is intended to be used where the relative position of the engine and the instrument board are such as to render possible the use of a flexible shafting drive direct from the engine to the indicator. It eliminates many of the disadvantages associated with the centrifugal type.

The instrument consists essentially of a circular 4-pole permanent magnet mounted on a shaft which is directly connected to the drive from the engine, and a drum or cup of a special alloy arranged so that the magnet revolves inside it, the amount of overlap being adjustable. The eddy currents generated in the drum cause it to tend to rotate with the magnet, and this rotation is restrained by means of a coil spring attached to the shaft carrying the drum. Balancing of this torque against the spring results in the drum rotating by an amount directly proportional to the speed of rotation of the magnet, and a pointer mounted on the end of the drum shaft reads against a circular scale graduated in r.p.m.

In the accompanying semi-diagrammatic drawing of the mechanism of the tachometer, the drum, G, is, for clearness, shown withdrawn from the magnet, M, but in the instrument as assembled, the drum overlaps

the magnet for the greater part of its length.

Maintenance

This instrument is thoroughly robustly constructed, and the main shaft, carrying the magnet, runs in ball bearings. It thus requires nothing in the way of maintenance beyond, possibly, the occasional replacement of a broken glass, which is carried out by simply removing the outer snap ring that holds it in place. Any further attention which the instrument may require must be carried out in a properly equipped repair shop, as this is bound to involve checking the calibration, for which a stroboscope or other means of determining r.p.m. accurately is essential. An apparent "zero error" of even 50 r.p.m. when the tachometer is at rest may be ignored, as this instrument does not come into correct calibration before reading a speed of 300–400 r.p.m.

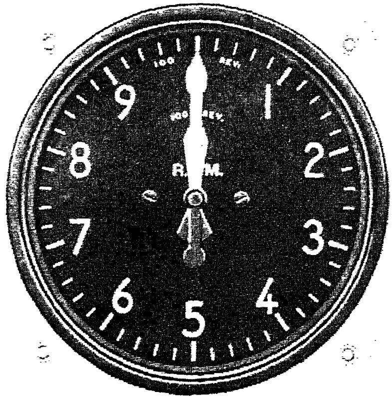


Fig. 31.—Electrical engine-speed indicator (sensitive type)

Installation is carried out as for all other instruments of the same general make-up. Care should, however, be taken that the flexible drive enters the coupling at the back of the instrument as straight as possible, and, to facilitate this, straight back and angle couplings are provided as alternatives.

Details for instrument-board cut-out, etc., are given in the accompanying sketch. The angle coupling for the flexible drive increases the overall length back to front by about $\frac{3}{8}$ in.

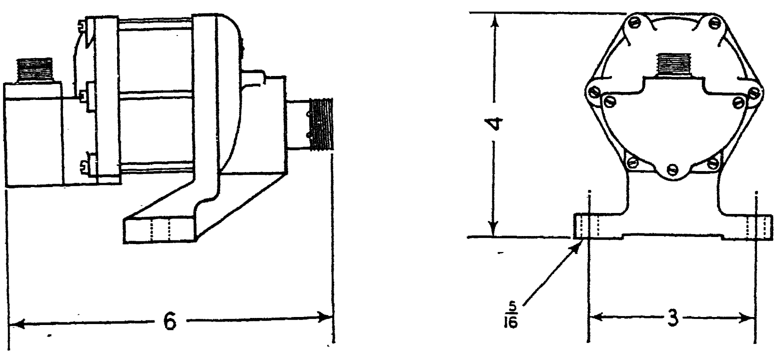


Fig. 32.—Installation diagram for electrical engine-speed indicator—generator

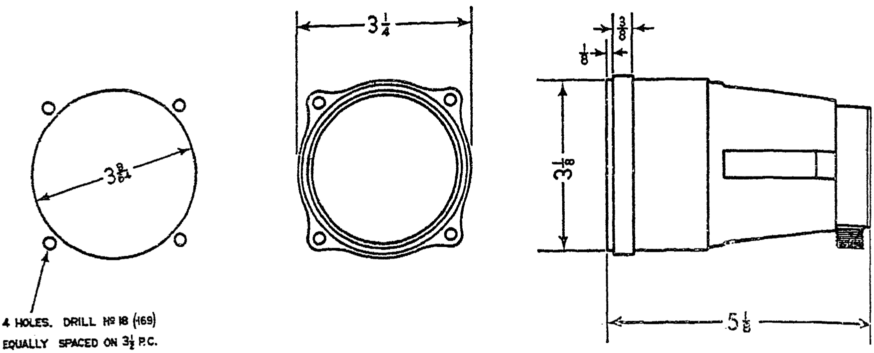


Fig. 33.—Installation diagram for electrical engine-speed indicator—dashboard instrument

ELECTRICAL ENGINE-SPEED INDICATOR OR TACHOMETER

This instrument embodies the same principle of magnetic drag for the actual operation of the pointer as has already been described for the magnetic tachometer. In this case, however, transmission between the engine and the instrument on the dashboard is achieved by simple electrical means instead of a mechanical drive. A small 3-phase A.C. generator is mounted on or close to the engine, and is driven from it by suitable means, usually a short length of flexible shaft, and a small synchronous motor is embodied in the tachometer itself and serves to rotate the magnet of the magnetic drag coupling.

This motor runs, of course, in exact synchronisation with the generator, and only an ordinary 3-core electrical lead is needed to connect from engine to dashboard. This means that distance between engine and instrument board presents no difficulties, and, further, the tachometer itself is independent of length of lead in respect both of accuracy and original calibration, i.e. any tachometer will operate successfully with any generator and with any reasonable length of lead connecting the two, thus giving this type of instrument a marked advantage over the earlier type of electrical tachometer, in which the indicator operates on the voltmeter principle.

The generator is so designed as to be independent of direction of rotation, i.e. the indicator functions correctly in whichever direction the generator is rotated, provided, of course, the leads from generator to indicator are correctly connected up in respect of phase sequence. The correct connections are clearly shown on the terminal boxes of both instruments. Being without brushes, sparking is impossible in either generator or indicator, the danger of interference with the aeroplane's radio being thus completely eliminated. This provides a further advantage attaching to this instrument as compared with the "voltmeter" type.

Two types are made, one with a circular scale covering 2,000 r.p.m., reading 500–3,500 r.p.m., in which case the single pointer makes $1\frac{1}{2}$ revolutions in reading from 500 to 3,500 r.p.m., and a "sensitive" type with a much more open scale over which the main pointer makes one revolution for 1,000 r.p.m. and permits of readings to 5 r.p.m. or even closer. This sensitive instrument carries a second, shorter pointer, which revolves at one-tenth the rate of the larger one, i.e. indicates in units of 1,000 r.p.m.

Both types are fully compensated for temperature changes, and the precision of the gearing and the use of ball bearings for the main shaft carrying the magnet and of jewelled bearings for the handstaff carrying the pointer reduce friction to a minimum and result in lag being negligible.

Maintenance

Service maintenance of this tachometer, as with the magnetic type, is limited to the replacement of a broken glass, but the instrument is so robustly constructed that other maintenance is not likely to be required. Should further attention be needed, this must be given in a properly equipped repair shop, where the special facilities required for checking the calibration are available. With the sensitive type a "zero error" up to some 50 r.p.m. may again be ignored, as the instrument does not come into calibration till 300–400 r.p.m. is reached.

Installation is carried out as already described for other instruments, and details of the instrument-board cut-out, etc., and for mounting the generator unit on the engine or engine mounting are given in the accompanying sketches.

K.B.B. COMPASSES

The series of K.B.B. aircraft compasses covers a comprehensive range of types, including the standard Air Ministry patterns, both for navigation and observation purposes, and the "K.B.B." range of Civil types, both for ordinary navigation and for various special purposes. These compasses have been in general use in aeroplanes for over twenty-five years, and a K.B.B. design was the first to be adopted by the Air Ministry as standard. The series in production to-day represents a highly advanced development in compasses for use in aeroplanes. The Service and Civil ranges correspond closely in the main features of design, but the Civil types have a modified magnet system which is quicker in reaction than that in the Service types and is consequently preferred by many civil pilots.

Full particulars of the whole range would be beyond the scope of this article, but all embody the same principles and conform to the same general design, so a brief description of a typical instrument, the K.B.B.4, will serve the present purpose.

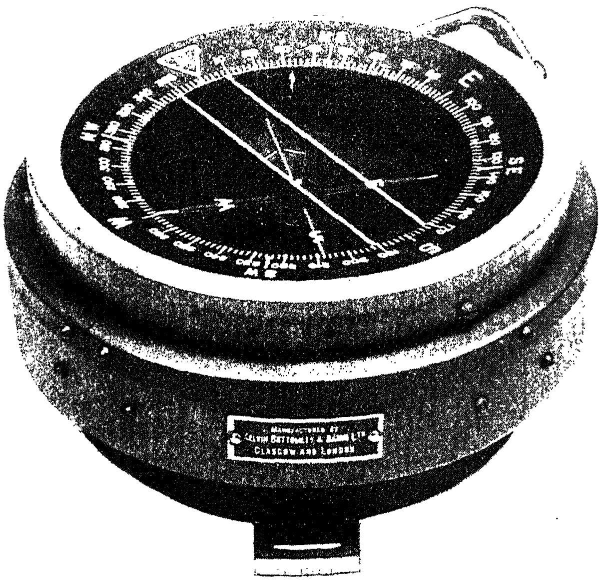


Fig. 34.—K.B.B.4 COMPASS

Description

The compass unit proper consists of a glass-topped metal "bowl," completely filled with a special spirit, which contains the multiple magnet element, carried on an inverted pivot of special design. This magnet element does not carry a "card," but on it are mounted four light arms or pointers, which indicate the N.S.E.W. points.

Immediately above and surrounding the periphery of the bowl itself is the "verge ring." This ring is free to rotate concentrically with the bowl, and can be firmly fixed on the bowl by a simple locking lever. On the ring is engraved a scale 0° to 360° and the N.S.E.W. points are also marked. Across the N.-S. diameter of this ring two parallel wires—the "grid wires"—are stretched, and these wires, the four arms of the magnet system, the N.S.E.W. points, and, in some cases, the 10° lines on the verge ring are luminised with radium compound. At one point near the periphery of the compass bowl, a "lubber line"—also luminised—is provided, so positioned as to read against the scale on the verge ring. In mounting the compass in an aeroplane it is essential, of course, that this lubber line should coincide with or be parallel to the fore-and-aft axis of the aeroplane.

The complete compass unit is inserted into a stout bowl-shaped outer casing, in which it is supported on two lateral pivots and carried on a specially sprung and cushioned mounting to protect it from vibration and damage. This outer casing is provided with feet or some suitable form of bracket for mounting in the aeroplane.

This arrangement of magnet element, lubber line, verge ring, and grid wires enables the aeroplane to be flown on a desired course with complete ease and accuracy. The verge ring is first freed and rotated until the scale mark for the required course coincides with the lubber line. If the aeroplane is then steered so that the N. and S. pointers of the

magnet element are lying parallel with the grid wires, it is and can be easily kept on the desired course.

Maintenance

The only servicing maintenance required for these compasses consists in (*a*) a check at regular intervals for friction in the magnet element, and (*b*) an occasional test of the efficiency of the anti-vibration mounting.

To check friction in the magnet element, remove the compass from the aeroplane, place it, preferably level, on a wooden table free from iron or steel nails, etc., and allow to settle for, say, 5 minutes. Then, tapping the cover glass lightly, set the grid wires parallel to the N.-S. line of the magnet system. By means of a magnet deflect the pointer slowly 10° and keep at that deflection for at least 30 seconds. Remove the magnet to a distant position, where it cannot affect the magnet system, and allow the pointer to resettle, *without* tapping. Then, avoiding any jarring or vibration, carefully reset the grid wires parallel to the N.-S. pointers and note the reading on the verge ring against the lubber line. Now, again using the magnet in the same manner, deflect the pointer 10° in the opposite direction, settle, reset the grid wires, and again read the verge ring. The difference should not be more than 2°. If it is, an undesirable amount of friction has developed, and the compass should receive attention.

To test efficiency of anti-vibration mounting place the hand *lightly* on the cover glass and, with a rotary motion of the hand, move the bowl in the horizontal plane. The bowl should move freely, and there should be no sound of *metallic* contact. Similarly, move the bowl up and down about $\frac{1}{8}$ in. in all, when it should also move freely and easily without sound of metallic contact. A dull sound of the frame hitting the cushioned stops may be heard at the end of the travel, but this is normal.

Any repair or other attention which a compass may be found to need should only be carried out by a properly equipped compass-repair shop or by the makers.

Installation

Installation merely involves securely mounting the compass in some suitable position in the cockpit, but every care must be taken to ensure that the diameter of the bowl which terminates on the lubber line is exactly coincident with or parallel to the fore-and-aft axis of the aeroplane.

A micro-adjustable corrector, operated either by milled heads or a separate key, is fitted at the bottom of each compass. After installation this should be used to correct for any deflection caused by the presence of magnetically active material in the aeroplane. Instructions for the adjustment of the compass are given in the Air Ministry's " Instrument Manual " (A.P. 1275).

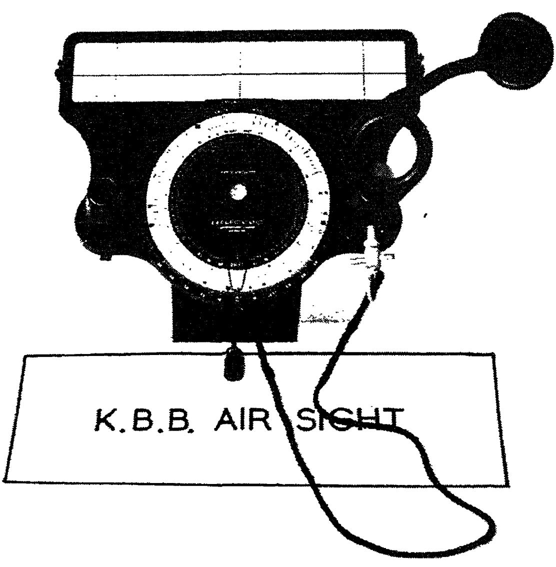


Fig. 35.—K.B.B. AIR SIGHT

K.B.B. AIR SIGHT

The K.B.B. air sight is an entirely novel instrument which has recently been introduced to enable the pilot or navigator of an aeroplane to determine true ground speed and/or drift by simple and straightforward means, essentially direct sighting and timing.

The basic features of the instrument are a longitudinal wire—the "drift wire"—with three cross-wires—the "timing wires"—at right angles to it and an eyepiece fixed as to plane with respect to the wires, but mountable in two alternative positions, fore and aft, through which the apparent travel of an object on the ground—land or sea—along the drift wire from one timing wire to another can be accurately observed and timed.

The trigonometrical basis on which the instrument is designed is such that, if the aeroplane is flown so that the "sighted" object travels exactly along or parallel to the drift wire from the timing wire at one end to that at the other, the distance travelled by the aeroplane is the same as the height of the aeroplane above the ground.

Thus if, for example, the altimeter—duly corrected for the prevailing barometric pressure at sea-level—shows the aeroplane to be flying at 2,500 ft. and the time for the traverse, as described, is 15 seconds, the aeroplane has travelled 2,500 ft. in 15 seconds. Thus a single observation, carried out as described, and requiring the aeroplane to be kept level and on a steady course for a relatively few seconds only, will give a reasonably accurate direct determination of ground speed. For greater accuracy, three or more determinations should be made, keeping at the same height, and the mean of the times recorded used for the speed computation.

With a *steady* rate of climb or descent, if the altitude is read at the beginning and at the end of the timing observation, and the average used for the computation, the accuracy of the ground-speed determination is not interfered with.

The main base plate of the instrument, on which the drift and timing wires and the eyepiece are mounted, is free to rotate on a vertical axis. A degree scale, the "drift scale," is engraved on this plate, concentric with the axial shaft on which it rotates. A pointer, the "drift pointer," is rigidly attached to this shaft and reads against the drift scale when the latter is rotated with the main plate. The instrument is so mounted in the aeroplane that when the drift scale reads 0 against this pointer, the drift wire is parallel to the fore-and-aft axis of the aeroplane. Thus, by rotating the base plate until an object on the ground, as viewed through the eyepiece, appears to travel along or parallel to the drift wire, the angle of drift can be read off direct from the position of the pointer against the drift scale.

A further use to which this air sight may be put is provided by an adjustable sight at each end of the drift wire, and a full 360° "bearing scale" which is engraved on a plate recessed into the base plate, concentric with the drift scale. This bearing scale can be rotated in angular relationship with the base plate and secured in any desired position by a friction device, thus rotating, after being so secured, with the base plate. By means of this and the above-mentioned sights, the instrument may be used as a pelorus for taking bearings and for checking the compass adjustment.

Means are provided for levelling the sight for taking observations, and the complete instrument is mounted on a standard wedge plate. By installing a number of standard sockets or brackets to fit this wedge plate in a number of different positions in the aeroplane, provision can be made for sighting objects in practically any position relative to the aeroplane.

A circular computator is also mounted on the central axis, concentric with it, by means of which a single setting of observed height against observed time permits of ground speed being read off direct.

Maintenance

The only ordinary servicing maintenance which this instrument is likely to require is in case of damage to the drift and timing wires. These are, in fact, not wires at all, but fine and very strong silk cords which are kept in place and in tension by a simple arrangement of springs. The complete system of cords and springs can be detached as a whole, the cords renewed and the system replaced. A diagram illustrating how this is done is supplied with each instrument.

For any other attention which the sight may require it must be sent to a properly equipped repair shop, preferably to the makers. It is, however, so robustly constructed that, with reasonable care, it should stand up to ordinary use without requiring any attention for a considerable period.

The air sight is intended chiefly for use in the cockpit, and since it

relies upon an oblique view of the ground, can be operated through the window. This feature is especially valuable in flying-boats, as no cutting of the hull is demanded.

Moreover, the sight is extremely useful over sea and flat terrain, since the possibility of using either port or starboard and either fore or aft sights at either position enables every advantage to be taken of faint shadows, etc., for taking observations.

THE SMITH AUTOMATIC PILOT

THE Smith automatic pilot is intended to relieve the pilot of an aircraft from the monotonous duties of piloting on long flights or under bad weather conditions, and since it is able to control the aircraft with much greater accuracy than the most skilled human pilot, its use is conducive to greater safety and economy, as well as enabling the pilot to devote his almost undivided attention to the important duties of navigation.

Provided that an aircraft is fitted with a suitable equipment of instruments for blind flying, a skilled pilot can fly an aircraft in almost any weather conditions, but the physical and mental strain of flying in bad conditions with poor visibility is considerable, and when, in addition, the pilot is faced with the task of navigating the aircraft to its destination, the risk of disaster can become very serious. By the use of the Smith automatic pilot, the pilot is relieved of his ordinary work of controlling the aircraft and he can devote himself to the work of navigation or to the operation of the radio equipment, and thus, under bad weather conditions, a far higher standard of safety is ensured.

Used Exclusively by the Royal Air Force

It is important to stress, however, that the Smith automatic pilot is not just a "gadget" intended to relieve the pilot of his normal duties. It is not a mere "blind-flying instrument" adapted to the control of the aircraft, but is a mechanism of the highest reliability and precision, and although its more general use is for the control of an aircraft on ordinary commercial routes, its great accuracy renders it of invaluable service for such work as aerial survey by photography or for precision bombing. It may here be remarked that the Smith automatic pilot is the design which has been used exclusively throughout the Royal Air Force for eight years. The unique accuracy and reliability of the Smith automatic pilot enable it to withstand the most arduous conditions encountered in service in the Royal Air Force.

An aircraft controlled by the Smith automatic pilot will seldom deviate from its course by more than 4° or 5° in an hour, and there is thus not the slightest necessity for frequent checking of the course by reference to the magnetic compass.

The Smith automatic pilot depends for its operation on two gyroscopes which are driven by compressed air at a pressure of 35 lb./sq. in. The system operates by compressed air throughout, and not only

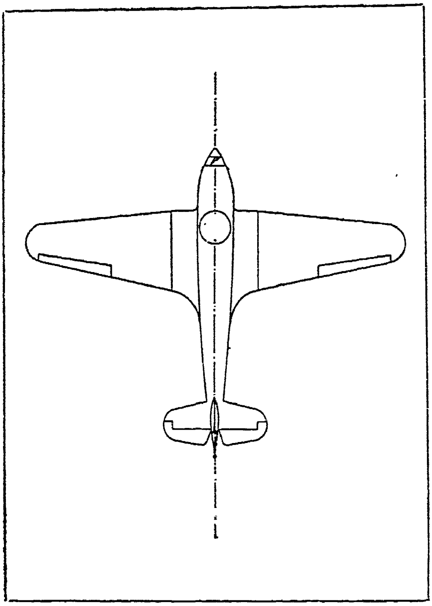


Fig. 1.—Showing the normal relative positions of aircraft and rudder gyroscope

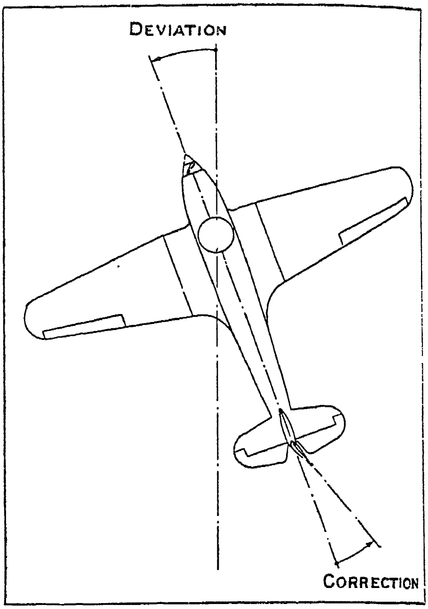


Fig. 2.—The aircraft has deviated from its course but the axis of the gyro remains undisturbed

does this tend towards lower weight but in addition much greater reliability is obtained, since delicate pneumatic-hydraulic relays are rendered unnecessary and the inevitable troubles due to changes of viscosity and leakage of oil are avoided altogether. Furthermore, the direct operation of the servo-motors by compressed air results in an important reduction in the lag of the controls. A reduction of the servo-motor lag is of vital importance, since far better damping of aircraft oscillations is thereby obtained.

Elementary Principles of the Smith Automatic Pilot

In order to understand the elementary principles of the Smith automatic pilot, it need only be remembered that a gyroscope (which consists of a "flywheel" rotating at high speed in a special form of mounting) possesses the property of tending to maintain its axis fixed in a given direction. A perfectly balanced and freely supported gyroscope spinning at high speed will in fact maintain the line of its axis fixed directionally almost indefinitely, no matter how the mounting itself may be moved.

Suppose that such a gyroscope is installed in an aircraft, then whatever direction the aircraft may take or however disturbed the weather conditions may be, the axis of the gyroscope will continue to point in the same direction as when it was started.

If the aircraft should deviate from its steady course, the angle through which it has turned can be readily ascertained by reference to the gyroscope.

Rudder Control

In the Smith automatic pilot, the gyroscope which controls the rudder is installed so that normally its axis lies fore-and-aft in the aeroplane, as shown in Fig. 1.

If the aircraft should deviate from its course as shown in Fig. 2, the axis of the gyroscope will no longer lie fore-and-aft in the aircraft, and this departure actuates a small air valve which is so arranged that it causes the aircraft rudder to be applied through the agency of a "servo-motor" in order to correct the deviation.

Aileron Control

The same gyroscope is used to control the elevators of the aircraft when a pitch disturbance occurs, but a second gyroscope is employed to control the ailerons. As in the case of the rudder control, deviations of the aircraft in pitch and roll operate small air valves which control the movements of the appropriate aircraft controls. The sensitivity of these valves is such that a deviation of the aircraft of about a tenth of a degree is sufficient to cause a correcting movement of the appropriate control.

A further important factor is that the magnitude of the movements of the aircraft-control surfaces is arranged to be proportional to the magnitude of the deviation. Thus, a minute deviation results in a similarly minute movement of the controls, while a large deviation results in a proportionally greater correcting movement. As the deviation is corrected, however, and the aircraft gradually returns to its course, the correcting movement of the control surface is progressively reduced and thus all harshness and over-correction is avoided. The pneumatic system employed is ideal for the control of these small movements.

The main gyroscopic units of the Smith automatic pilot are not fitted in the dashboard of the aircraft. Instead, they are installed in almost any convenient position in the aircraft (e.g. under the pilot's seat), and controlled from the pilot's cockpit. This arrangement was adopted because it was felt desirable that entirely independent means should be provided to ensure against the failure of any piece of equipment essential to the safety of the aircraft. By installing the automatic pilot in some other part of the aircraft, an entirely independent set of normal "blind-flying" instruments can be installed in the dashboard for use in the event of a failure of the automatic pilot.

Furthermore, the arrangement of the Smith automatic pilot enables it to be installed in almost any aircraft without the necessity for a

specially designed layout or the construction of a special instrument panel, and it possesses the added advantage that the design of the gyroscopic apparatus is not unduly restricted by considerations of space. The designer is therefore free to adopt a form of construction and to employ gyroscopes of sufficient size to ensure the utmost reliability and accuracy.

Pilot's Controls

The pilot is provided with a main control cock for bringing the automatic pilot into action, and he is also provided with certain additional controls for executing turns while under automatic control and for varying the pitch attitude, which he is able to adjust between the limits of 5° climb and 10° dive. The operation of these controls is such that the transitions are smooth and gentle, even if the control lever is moved suddenly from one extreme position to the other.

In addition to these controls, a lever is provided by which all three of the servo-motors may be mechanically disconnected from the aircraft controls in an emergency—for example, if a vital part of the pneumatic system or a servo-motor were damaged by a bullet.

The whole system is operated by a compressed-air supply provided by a small and light compressor which may be driven either by the engine, or by a windmill, as desired by the operator. The design of the compressor system is such that a trace of oil vapour becomes mixed with the compressed air and serves to maintain continual lubrication to all the moving parts. An air drier, containing silica gel, is also provided to guard against the risk of ice forming anywhere in the system when the weather conditions are such that ice formation is a possibility.

The long period during which the Smith automatic pilot has been developed, and the very wide experience which has been gained as a result of its almost universal use throughout the Squadrons of the Royal Air Force, have resulted in the attainment of an exceptionally high degree of *accuracy, reliability,* and *safety.*

SIMPLE OUTLINE OF GYROSCOPIC PRINCIPLES

To gain a clear idea of the operation of the Smith automatic pilot, some knowledge of the elementary principles of gyroscopic action is required, and it is therefore necessary to describe briefly the properties and functioning of a simple gyroscope.

It is one of the fundamental laws of mechanics enunciated by Newton that any body will continue in its state of rest or of uniform motion in a straight line unless some force acts upon it to change its uniform state. One of the consequences of this law is that any rotating body tends to oppose any change in the direction of its axis. (*Note.*—One must distinguish carefully between a change in *direction* and a change in *position*. To make this clear, consider the flywheel of a motor-car which

rotates about an axis parallel to the direction of motion of the car. As the car travels forwards, the flywheel obviously changes its *position* continually, but it is only when the car is turning a corner that the axis of the flywheel is changing its *direction*. It is only in the latter case that gyroscopic effects are produced, although in the case of a motor-car the effect cannot be appreciated. Similarly, the road wheels of the car are continually changing their *position*, but only when the car is turning are they changing their *direction*.)

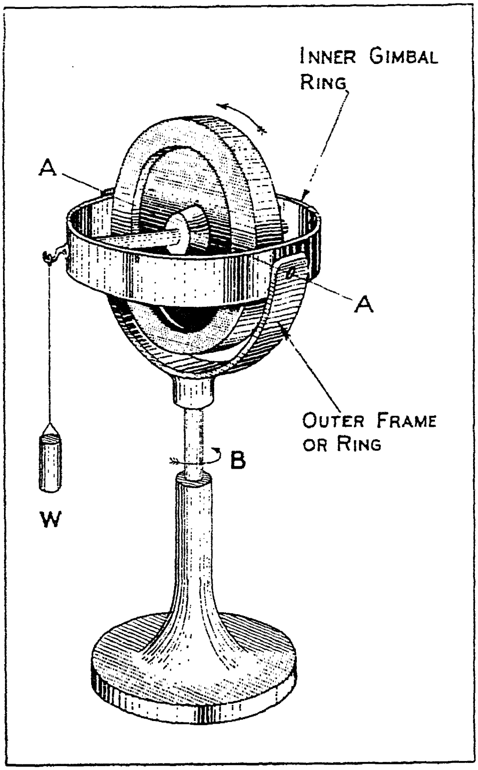


Fig. 3.—SIMPLE GYROSCOPE AND GIMBAL RINGS

As stated above, any rotating body tends to oppose a change in the direction of its axis of rotation. The greater the speed of rotation, the greater is the tendency to maintain the direction of the axis fixed, and a carefully balanced gyroscope spinning at high speed will maintain the direction of its axis with a high degree of accuracy. A gyroscope may therefore be said to provide a datum line in space.

A Simple Gyroscope

A simple gyroscope consists merely of a flywheel which is capable of rotation at high speed, and which is mounted in pivoted " gimbal frames " or " rings," as shown in Fig. 3. The gyro wheel itself is carried by ball bearings in an inner ring which, in turn, is supported in an outer frame by the pivots A—A. The outer frame is also free to rotate about its vertical axis, and the gyroscope is therefore said to possess three degrees of freedom, i.e. it can rotate about its own axis, it can rotate about the horizontal axis A—A, and it can also rotate about the vertical axis. These three axes are normally all at right-angles to each other.

For the moment, it will be assumed that the pivots A—A, which support the inner gimbal ring, and also the bearing B, which permits the whole system to rotate about the vertical axis, are mechanically perfect

and possess no friction. Although this is obviously impossible in practice yet the pivots and bearings of all gyroscopes must be as nearly perfect as possible, since friction tends to cause inaccuracies, as will be seen later.

Effect of applying an External Force

Let us suppose that the gyroscope has been carefully balanced and is spinning at high speed in the direction shown in Fig. 3. Unless some external force is applied to the gyroscope, the direction of its axis will remain fixed, no matter how the base may be moved. The application of an external force, however, will cause the gyroscope to behave in an apparently peculiar manner.

Suppose that a torque is applied to the inner gimbal ring about the axis A—A by the addition of a weight W as shown. The addition of this weight will cause the spinning gyro wheel, together with the supporting rings to rotate or "precess" about the vertical axis B in the direction shown by the arrow, and, assuming that the bearing B is completely free from friction, the weight W will not tend to fall as it clearly would if the wheel were not rotating.

Angular Motion or "Precession"

This phenomenon will be familiar to those who have studied the behaviour of spinning tops. For our purpose it is sufficient to remember that *a torque which is applied about an axis at right angles to the axis of spin will produce an angular motion or "precession" about an axis which is at right angles both to the axis of spin and to the axis of the applied torque.* Thus, in Fig. 3, the weight W applies a torque about the axis A—A which is at right angles to the axis of spin, and this torque does not result in angular motion about the axis A—A as one would at first expect, but it results in angular motion about the vertical axis B, which is at right angles both to the spin axis and to the axis of the applied torque.

Similarly, if a torque were applied to the outer frame in the direction shown by the arrow D in Fig. 4, the inner ring and gyro wheel would tilt or precess about its pivots A—A, and the outer frame would actually remain motionless.

It must be remembered that a torque need not necessarily be applied by means of a weight. It may be applied by a spring, or by friction about the pivots, and it is for this reason that friction at the various pivots tends to reduce the accuracy of the gyroscope.

The Effect of Friction

To illustrate the effect of friction, consider again the gyroscope shown in Fig. 3. As has been stated, the application of the weight W will cause the gyroscope and its supporting rings to precess about the vertical axis B, and the weight W will not tend to fall. If, however, there is appreciable friction at the bearing B, this friction will exert a torque tending to

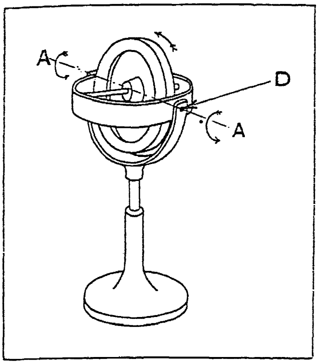


Fig. 4.—SIMPLE GYROSCOPE WITH A DIFFERENT TORQUE

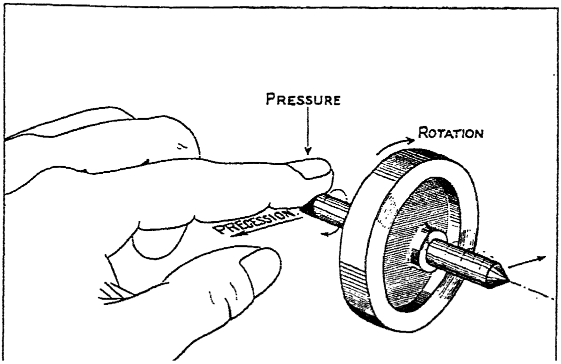


Fig. 5.—DIRECTION OF PRECESSION

If a torque is considered as being applied by the pressure of a finger on the axis of the gyro wheel, then the direction of precession will be such as would occur if the axis were to *roll* in contact with the finger.

oppose the vertical precession, i.e. in a direction opposite to that shown by the arrow. Such a torque about the vertical axis, whether it is due to friction or otherwise, will result in a precession of the gyroscope about the axis A—A in such a direction that the weight W will tend to fall.

It is convenient to remember that:

(1) Any torque about the horizontal axis of the inner gimbal ring will cause a precession "in azimuth," i.e. about the vertical axis, and

(2) Any torque about the vertical axis will cause "topple," i.e. a precession about the horizontal or "pitch" axis.

(3) The direction of precession of a gyroscope in response to an applied torque will be such that a precession of 90° would bring the axis of rotation of the gyro wheel to coincide with the axis of the applied torque in such a way that the gyro wheel is rotating in the same direction as the applied torque.

A convenient method of memorising the direction in which a gyroscope precesses in response to an applied torque is to imagine that the torque is applied by the side of a finger pressing against the rotating shaft of the wheel, as shown in Fig. 5. The direction of the resulting precession is that which would result if the shaft were to roll in contact with the finger.

Balance

From what has been said above, it will be clear that a precession about the vertical axis B is due to a torque about the horizontal axis A—A. Such a torque may be due to a lack of balance of the gyroscope and inner gimbal ring, and it is therefore evident that if the gyroscope is to remain

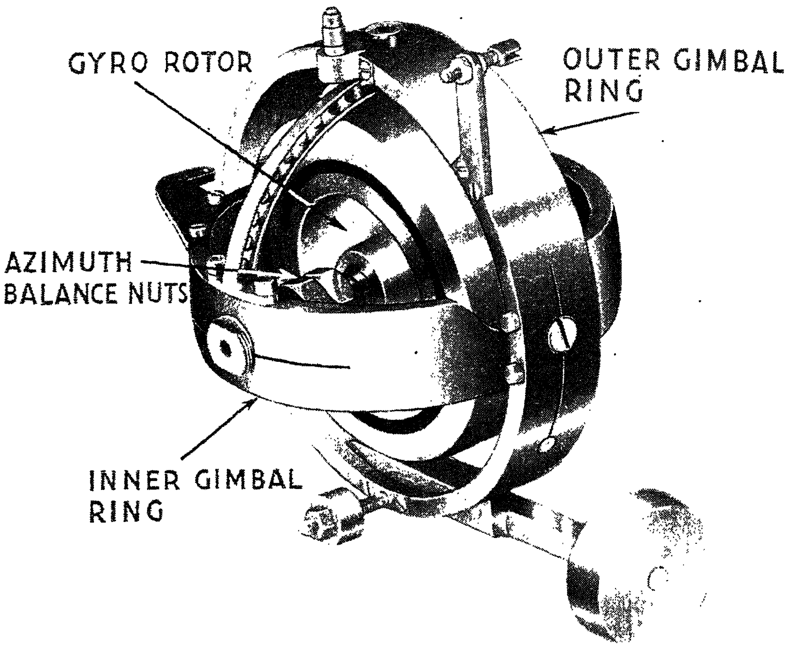


Fig. 6.—Gyroscope and gimbal rings of the rudder and elevator control unit

accurately located in azimuth, then the gyro rotor and the inner gimbal ring may be very carefully balanced. A view of the actual gyroscope and gimbal system of the rudder and elevator unit of the Smith automatic pilot is shown in Fig. 6, and on the shaft of the rotor may be seen a pair of nuts which are employed to adjust the final balance of the rotor and inner ring. One complete turn of these nuts will produce a change in azimuth precession of 30° per hour. This balancing, however, is very carefully carried out by the makers and should never be altered.

Precession of Gyroscope due to Earth's Rotation

We have seen that a perfectly balanced gyroscope tends to maintain the direction of its axis fixed in space. If such a gyroscope were placed at the North Pole with its rotor axis horizontal, it would appear to rotate with the celestial bodies ; it would in fact be a 24-hour clock. Similarly, if a perfect gyroscope were placed at the Equator, with its axis pointing

east and west, the rotor and the inner ring would rotate slowly around the horizontal axis of the inner ring, turning completely over once in every 24 hours.

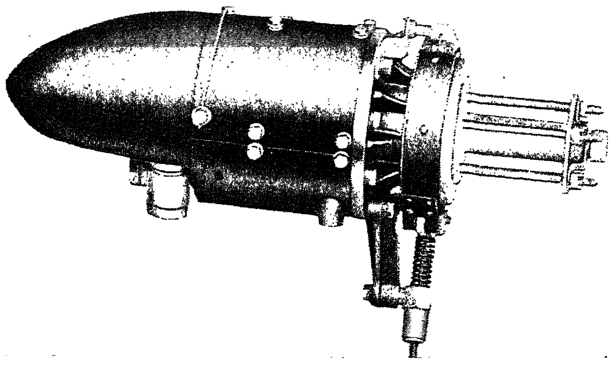


Fig. 7.—Windmill-driven compressor, Mk. III

It will be clear that at intermediate positions on the earth's surface, the gyroscope will appear to precess about both the axes of suspension at rates dependent on the latitude in which it is operating. It is easy to compensate, however, for the horizontal precession about the vertical axis by placing the inner ring slightly out of balance so as to produce a torque about the horizontal axis. This compensation, however, is only accurate for one latitude, and if the gyroscope is to be used on a route involving considerable changes in latitude, it is desirable to provide means for adjusting this balance in accordance with the latitude. This compensation is provided in the Smith automatic pilot.

The method of compensating for latitude changes is described in detail on page 77.

The second apparent precession due to the earth's rotation, i.e. that about the horizontal axis, requires some form of gravitational control if the inner ring is to maintain a constant attitude to the horizontal plane. When such a gravitational control is applied, it also takes care of such precessions of the inner ring as may be caused by the slight friction of the bearings of the outer ring. Unfortunately, no such compensation is readily available to correct precessions in azimuth, which may be due to friction about the axis of the inner ring, and a slow wander in azimuth is therefore to be expected, which necessitates occasional corrections to the course by the pilot.

In the Smith automatic pilot, the friction of the inner gimbal-ring bearings and the associated parts has been reduced to such an extent that this residual wander seldom exceeds the figure of 5° per hour.

COMPRESSED-AIR SYSTEM AND CONTROL EQUIPMENT

The motive power for driving the gyroscopes of the Smith automatic pilot, and operating the aircraft-control surfaces to maintain the aircraft on its intended course, is derived from a self-contained air-compressor

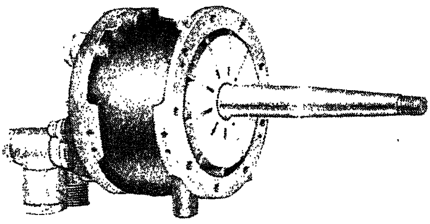


Fig. 8.—Showing eccentrically-placed rotor and sliding vanes of windmill-driven compressor

system which is designed to supply the requisite volume of dry compressed air at a pressure of 35 lbs./sq. in.

An important feature of the design of the compressor system is that the compressed air becomes charged with a trace of oil vapour, and this serves to maintain continuous lubrication of nearly all the moving parts.

Air Compressors

Two main types of air compressor are available, one of which employs a small windmill as the source of motive power, the other being adapted for direct drive from the engine. There are, however, two different models of the engine-driven compressor, as shown in the following list:

Windmill-driven type—
Air compressor, Mark III.

Engine-driven types—
Mark I. Type B. For Rolls-Royce engines.
Mark I. Type C. The standard engine-driven compressor for all other engines.

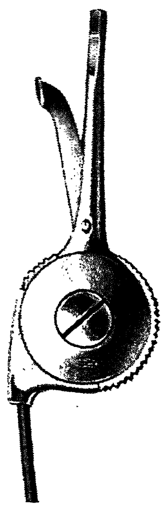


Fig. 9.—Brake lever for windmill-driven compressors

(*Note.*—The standard direction of rotation of all the air compressors is clockwise, viewed from the driven end. The type C compressor can, however, be supplied for anti-clockwise drive if necessary, but the compressor is non-standard in this form and must be specially ordered if required.)

The Mark III windmill-driven compressor is of the rotary-vane type and employs a rotor which revolves on its shaft in an eccentrically-placed outer casing, as shown in Fig. 8. The rotor is fitted with steel vanes which move in the slots of the rotor under the action of centrifugal force. Air is drawn in through the air inlet and is compressed by the rotation of the blades, finally being discharged through the outlet.

The efficient working of this type of compressor depends on a continuous supply of oil, which acts partly as a lubricant and partly as a seal between the blades and the casing. A small jet regulates the oil flow, and the compressed air is ejected through the outlet, carrying the surplus oil with it. The Mark III compressor is driven by a small windmill, of which there are several different

types available, according to the speed range of the aircraft on which it is to be used and according to the position of installation.

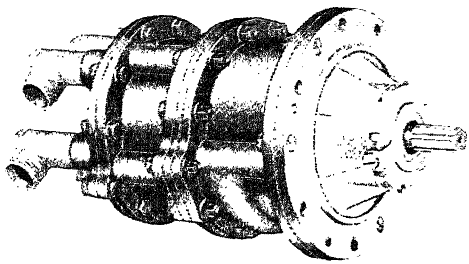


Fig. 10.—ENGINE-DRIVEN COMPRESSOR, MK. I, TYPE B, FOR ROLLS-ROYCE ENGINES

Compressor Brake Lever

The windmill-driven type of compressor is fitted with a Ferodo-lined brake which may be operated from the pilot's cockpit in order that the compressor may be stopped when the automatic pilot is not required in use.

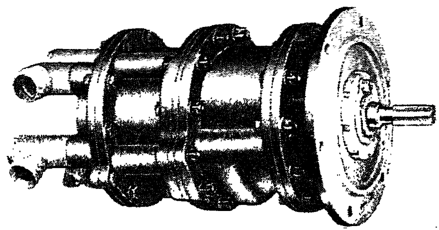


Fig. 11.—ENGINE-DRIVEN COMPRESSOR, MK. I, TYPE C

The brake lever (Fig. 9) is an ordinary Bowden control lever which is fitted with a ratchet to enable the brake to remain in the ON or OFF positions. By means of a single Bowden cable, it actuates the Ferodo-lined brake band which is attached to the compressor.

Note.—In installations where an air-intake throttle is not fitted, it is important that the brake should be applied only when the main control cock is at the OUT position. In this position the compressed air is allowed to escape to atmosphere, and there is consequently a negligible pressure in the compressor system. If the brake is applied in any other position of the main control cock, there will be a pressure of about 35 lbs./sq. in. in the system which, when the compressor is suddenly

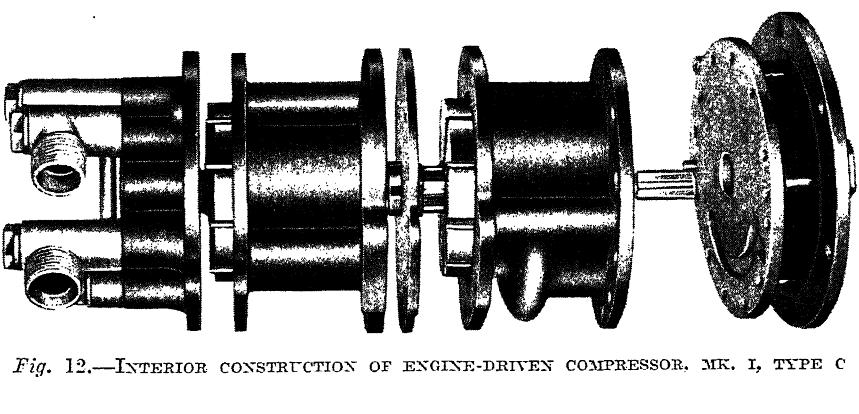


Fig. 12.—INTERIOR CONSTRUCTION OF ENGINE-DRIVEN COMPRESSOR, MK. I, TYPE C

stopped, will result in the supply of oil in the oil reservoir flooding the compressor and escaping out of the air inlet.

For similar reasons, the engine-driven type of compressor should not be stopped by shutting down the engine by which it is driven unless the main control cock is at the OUT position.

The engine-driven compressors are similar in principle to the windmill-driven model, but they employ two rotors, revolving in two cylinders which are bolted end to end. A single shaft carries both rotors, but the rotor casings are eccentric to each other in order to reduce the bearing loads. It should be noted that the two sections of the engine-driven compressors do not give "two-stage" compression: they work in parallel with each other to give the required output.

A short length of the shaft which transmits the drive from the engine to the compressor has a smaller diameter than the rest of the shaft. This reduced diameter acts as a weak link and prevents the possibility of damage to the engine in the event of a mechanical failure of the compressor, such as might be caused, for example, by a failure in the supply of lubricating oil.

OIL FOR COMPRESSOR SYSTEM

It is very important that the correct grade of oil should be used at all times in the compressor system, since a small quantity of oil remains suspended in the compressed air as a fine "mist" and serves to lubricate the valves of the gyroscopic system. The use of an incorrect oil is likely to cause "gumming" of the various valves. The following oil has been chosen after a long series of tests, and no other grade should be used.

Use only oil which complies with the British Air Ministry Specification No. D.T.D.44b.

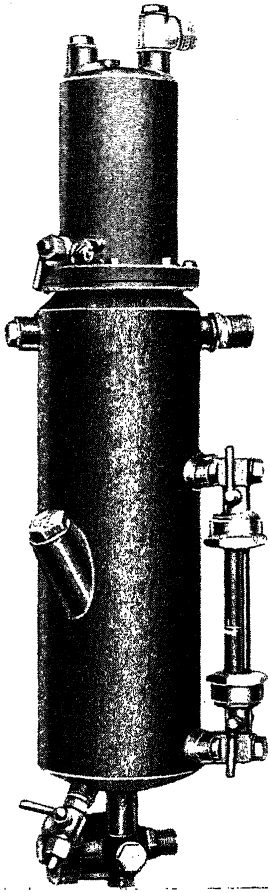
The following oils, which are commercially distributed throughout the world, comply with this specification :

Shell Anti-Freezing Oil.
Intava Utility Oil.
Intava Servo Fluid.

Oil Reservoirs

The compressed air and surplus oil from the air compressor is fed into the oil reservoir, which acts as a storage tank for the circulating oil supply to the compressor and also separates the oil from the compressed air on its return from the compressor. The incoming stream of compressed air and oil from the compressor is caused to impinge against a surface inside the reservoir, and this action causes most of the oil to separate out from the air.

Two types of oil reservoir are available, namely the Mark III and the Type II.



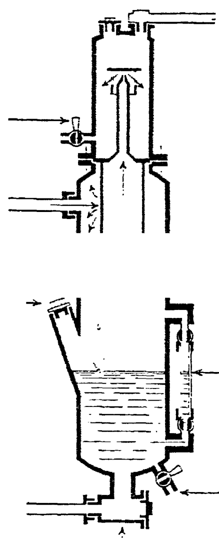


Fig. 13 (*left*).—Oil reservoir, mk. iii

Fig. 14 (*above*).—Interior of oil reservoir, mk. iii

The Mark III oil reservoir, which is illustrated in Figs. 13 and 14, consists, as may be seen, of an oil container which is fitted with a filler cap and a gauge to indicate the oil level in the container.

The oil in the reservoir should be maintained at the 1-pint level which is indicated on the gauge glass. Care must be taken not to over-fill with oil, and the oil level *must not exceed* the mark on the gauge glass. The reservoir should, however, always be filled up if the level of oil has fallen more than $\frac{1}{4}$ in. below the correct level. The oil level can be checked only when the air compressor is at rest, and in practice it will be found that the reservoir requires replenishment at intervals varying between 5 and 15 hours' use.

The bottom of the reservoir is fitted with a drain cock, and a filter through which the oil passes to the air compressor. It is desirable that

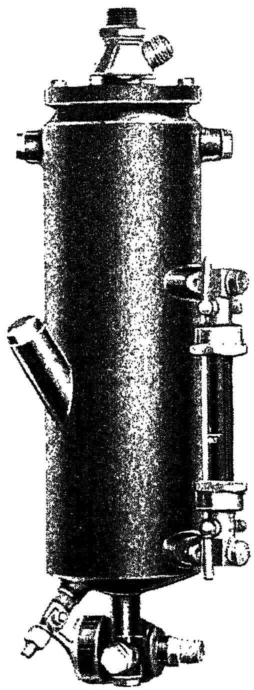


Fig. 15.—Oil reservoir, type II

this filter should be removed and cleaned after every 40 hours' use.

The top portion of the Mark III reservoir is known as the oil separator, and its function is to remove the surplus oil which still remains in the compressed air when it leaves the reservoir. As will be seen in Fig. 14, the air leaving the reservoir is caused to impinge against a flat plate and this action causes all but a trace of the oil to be deposited.

The oil separator is provided with a drain cock, which should be opened after every flight or after every 10 hours' use in order to drain off any accumulation of oil or water.

The Type II Oil Reservoir, Fig. 15, is similar in principle to the Mark III model, but it is smaller and lighter, since it does not incorporate the oil separator unit at the top.

By a re-design of the initial separating jet in the oil reservoir, it has been found possible to obtain satisfactory separation without the use of the oil separator.

The Type II Oil Reservoir requires replenishment after every 10 to 18 hours' use, to maintain the oil at the correct level.

Air-intake Throttle

This unit is fitted to the air inlet of the compressor, and serves to maintain a constant delivery pressure of 35 lbs./sq. in. over a wide range of speeds of the compressor.

It embodies a spring-loaded metallic bellows which operates a disc valve. The delivery pressure is applied to the bellows so that increase or decrease of delivery pressure respectively closes or opens the throttle and so automatically controls the delivery pressure.

Automatic Valve

From a consideration of Fig. 16 it will be evident that, if the design of the aircraft is such that the oil reservoir must be installed at a higher level than the air compressor, there is a possibility of the oil in the reservoir flooding the compressor when the compressor is not working and leaking out of the air inlet. To avoid such leakage, an automatic valve (Fig. 19) is inserted in the pipe line leading from the bottom of the oil reservoir to the compressor. The unit contains a spring-loaded mushroom-headed valve, and the strength of the spring is such that while it will permit the valve to open, and oil to pass freely through it, when the compressor is working and there is the normal operating pressure in

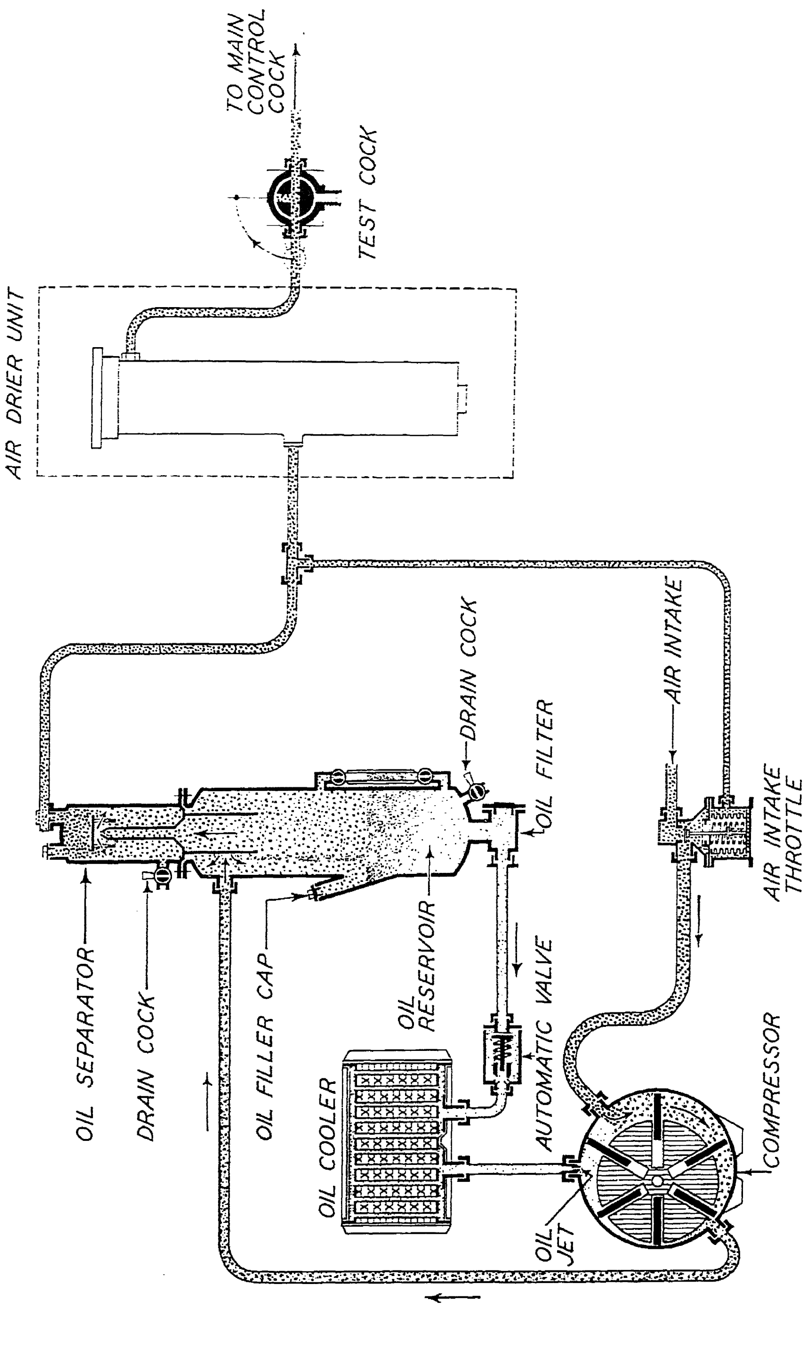


Fig. 16.—Diagram of complete air compressor installation

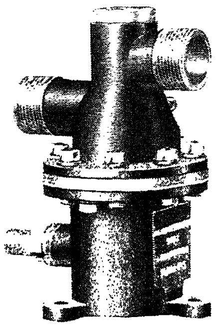


Fig. 17.—Air intake throttle, type II

the reservoir, yet it will not permit the passage of oil under the purely static pressure when the compressor is not in action.

In installations where the oil reservoir is located above the compressor, the valve is installed in the pipe line close to the compressor and, as stated, it serves to prevent the loss of oil when the compressor is not working. The valve is also used, however, in installations where the oil reservoir is located below the level of the air compressor, and in this case the valve is installed close to the bottom of the reservoir. As the valve will permit oil to pass through it in only one direction, it is employed in this case to prevent the drainage of oil from the compressor and the pipe leading to it when the filter at the bottom of the reservoir is removed for cleaning.

In all cases, the valve is installed with the arrow pointing along the pipe leading towards the compressor.

Air Drier, Mark Ia

If air is drawn in by the air compressor direct from the atmosphere, there is some risk, during weather conditions which include high relative humidity and low temperatures, that moisture may be deposited and freeze in the pipes, jets, or valves of the automatic pilot, thus putting it out of action. For this reason the gyroscope units of the automatic pilot are totally enclosed whenever the layout of the installations permits, and the air from the control units is returned again to the air intake of the compressor. In this way the same air is used again and again, and little moisture is introduced into the system.

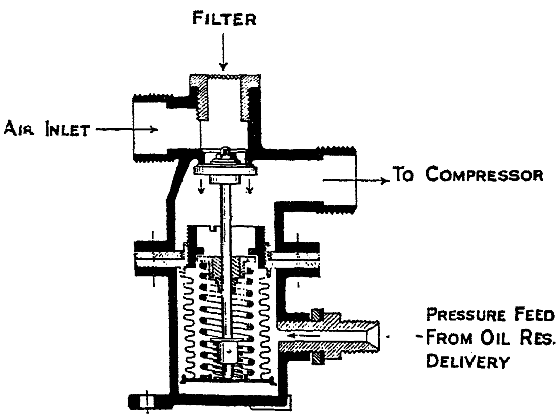


Fig. 18.—Interior arrangement of air intake throttle, type II

In order to eliminate this moisture, with its attendant possibility of freezing, an air drier is employed whose function

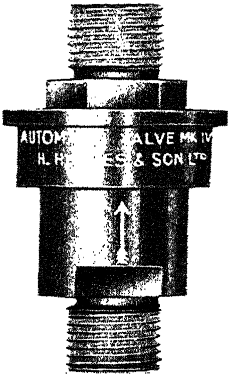


Fig. 19.—AUTOMATIC VALVE, MK. IV

is to extract the excessive moisture from the compressed air.

The drier consists of a steel cylinder having a lid at the top and two pipe unions at the side. Inside is a cylindrical container which is used to hold the drying agent, silica gel. The compressed air from the oil reservoir is passed into the lower union of the drier and impinges against a baffle plate inside. Thence it passes upwards through the drying agent in the inner container and the moisture is extracted from it. The air then passes away through the top union to the test cock.

The great majority of modern aircraft are constructed with enclosed cockpits and cabins, in which the temperature of the control units cannot fall below the freezing-point. In such installations the drier need not be employed, but when the installation is such that the temperature may fall below the freezing-point the drier should be used. Whenever possible, the " regenerative " system of returning the air from the control units for re-compression is employed and the " life " of the silica gel contained in the drier is then about 15 *hours*.

There are occasional cases, however, when the installation difficulties are such that a regenerative system for the air supply cannot be arranged and when the automatic-pilot mechanism is liable to be exposed to low temperatures. In such cases, the " life " of the silica gel is limited to about 5 *hours*, in weather conditions of high relative humidity.

It will be obvious that the life of the silica gel is entirely dependent on the conditions of use, and the operating conditions must therefore be borne in mind in fixing the periods for recharging the drier.

The drier can be recharged only on the ground. Recharging should be carried out as follows :

(1) Remove the top lid and extract the inner container.

(2) Remove the used filling and packing.

(3) Clean the inner container and place a piece of cotton-wool in the conical bottom of the inner container.

(4) Insert a gauze disc having a diameter equal to that of the inside of the inner container.

(5) Recharge with silica gel.

(6) Cover the silica gel with a further piece of cotton-wool and a further gauze disc.

(7) Replace the container in the outer cylinder, replace the spring, and fasten the lid securely.

In installations in which no air drier is included, a water trap is in-

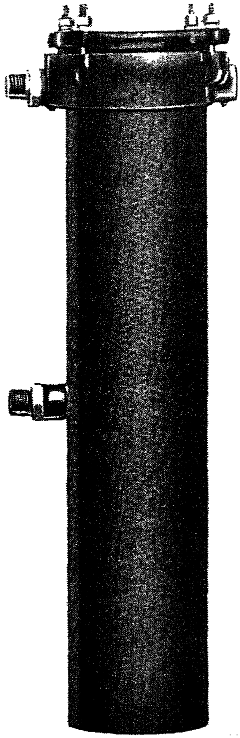


Fig. 20.—Air drier, Mk. *Ia*

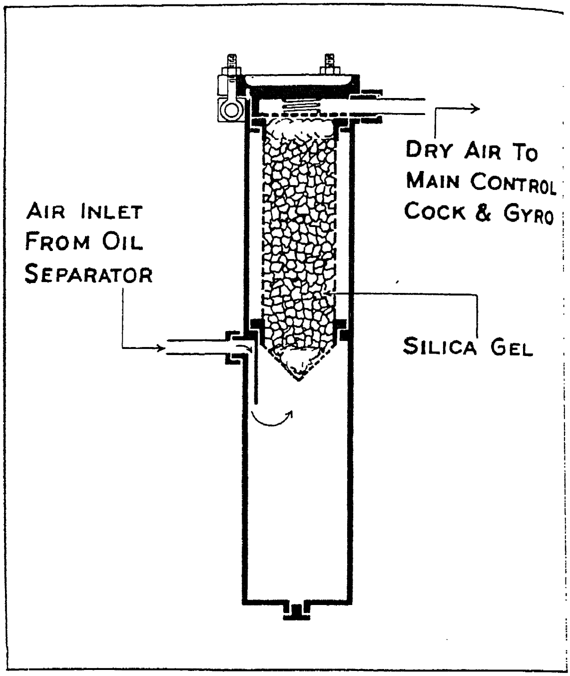


Fig. 21.—Interior of air drier, Mk. *Ia*

serted in the line leading from the oil reservoir to the main control cock. This trap must be drained after every flight.

Air-pressure Gauge

This unit is fitted in the pilot's cockpit, and indicates the pressure of the compressed-air supply. The correct pressure is between 30 and 35 lbs./sq. in., and the automatic pilot should not be used in normal flight if, for any reason, the indicated pressure is less than 28 lbs./sq. in. At high altitudes, however, the indicated pressure tends to fall.

It should be noted, however, that the above-mentioned pressures refer to conditions when the aircraft is flying at its cruising speed and the air compressor is running at its normal speed. It is frequently desirable to use the automatic pilot when the aircraft is descending in a glide with the engine throttled back, and since the air compressor will then be running at low speed, the pressure of the compressed air may fall considerably. *Provided, however, that the aircraft controls are not unduly "heavy" in a throttled glide at reduced speed, and provided that the compressed-air pressure does not fall below, say, 20 lbs./sq. in., the automatic pilot may be employed with perfect safety during gliding descents.*

Combined Pressure-gauge Unit

This unit is an alternative to the single pressure-gauge unit described above, and is designed to give two entirely separate indications, namely:

(*a*) The pressure of the main supply of compressed air; and

(*b*) The differential or resultant pressure being applied at any instant to the elevators of the aircraft.

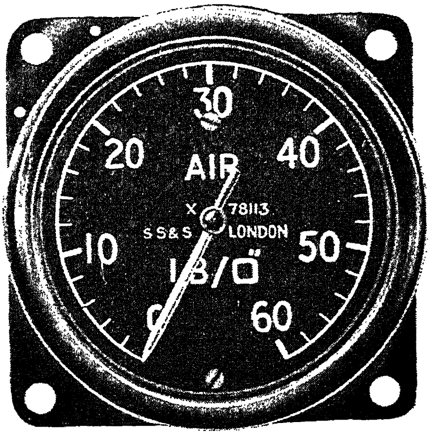


Fig. 22.—AIR PRESSURE GAUGE

The first of these indications is given by an ordinary Bourdon type of gauge. The second unit is a differential gauge, and indicates the difference between the pressures in the two sides of the elevator servo-motor. It is thus an indication of the resultant force being applied to the elevator. A constant indication in one direction on the gauge indicates that a constant load is being applied to the elevators to maintain the attitude of the aircraft, i.e. that it is either "nose-" or "tail-heavy," and the elevators should be retrimmed accordingly.

While it may be noted that incorrect trimming will not affect the attitude at which the automatic pilot flies the aircraft, the elevators should always be trimmed to give a central reading on the differential gauge.

Test Cock

This unit is intended to provide an easy means of connecting a supply of compressed air to the mechanism for the purpose of testing it when on the ground. It consists of a two-position cock, one position being marked "FLYING," and the other "TEST." In the former position the compressed air is allowed to pass straight through the cock from the compressor installation to the main control cock and thence to the gyroscopes.

In the "TEST" position, the cock isolates the compressor system and connects the pipe leading to the main control cock with a union on the test cock, by means of which easy connection may be made to an external supply of compressed air.

Main Control Cock

It is by the use of the main control cock (which controls the admission of compressed air to the various components of the automatic pilot) that the pilot of the aircraft brings the automatic pilot into action and cuts

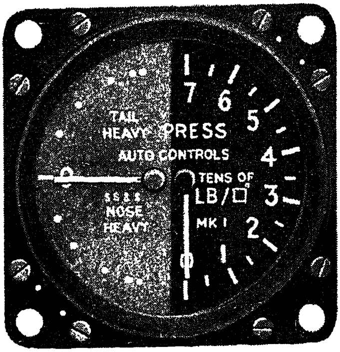


Fig. 23.—DIFFERENTIAL PRESSURE GAUGE

The right-hand pointer is an ordinary pressure gauge, but the left-hand pointer is a differential gauge connected to the elevator servo-motor, to give indication and warning of any constant load on the elevators.

it out when he requires to return to manual control. The cock has three positions: "OUT," "SPIN GYRO," and "IN." In the first position the supply of compressed air is released to the atmosphere. In the "SPIN GYRO" position the compressed air is connected only to the spinning jets of the gyroscopes and to the two relay valves, while in the third or "IN" position it is supplied also to the three main valves and to the three servo-motors, thus placing the automatic pilot in control.

When putting the automatic pilot into operation, the main control cock must be allowed to remain in the "SPIN GYRO" *position for at least five minutes before moving the lever to the* "IN" *position, in order that the gyroscopes may attain their correct speed.*

When taking-off or landing, the main control cock must always be in the "OUT" position.

As a safeguard against the risk of taking-off the aircraft with the main control cock in the "IN" position, and so permitting the supply of compressed air to reach the servo-motors before the gyroscopes are spinning at a safe speed, the main control cock is fitted with a safety device which consists of a spring-loaded piston valve which is operated by a cam on the handle of the cock. This piston valve prevents the compressed air being admitted to the servo-motors unless the cock is first turned to the "SPIN GYRO" position while the compressor is running. The safety device also operates and shuts off the supply of compressed air to the automatic pilot if, for any reason, the supply pressure fails. It can only be reset by again turning the cock to the "SPIN-GYRO" position. The detailed construction and operation of the main control cock will be clear from the following description.

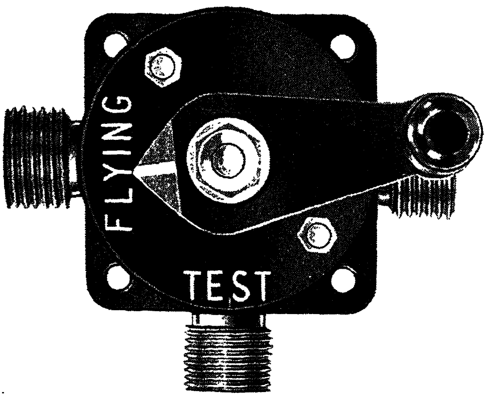


Fig. 24.—TEST COCK

Referring to Fig. 27 (*b*), which shows the main control cock in the "OUT" position, it will be seen that the air

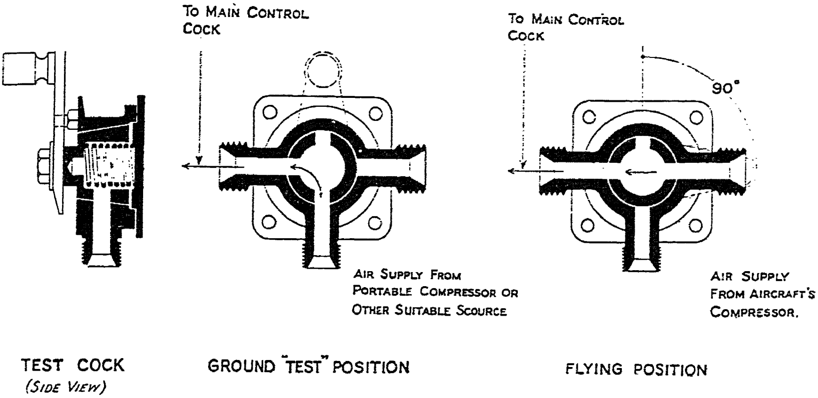


Fig. 25.—Interior arrangement of test cock in the "test" and "flying" positions

from the compressed-air system enters the cock, passes beneath the spring-loaded piston, and eventually escapes to the atmosphere. (In most installations the escaping air is led back to the air inlet of the compressor.) It will be noted that in this position of the cock the pipes leading to the spinning jets of the gyroscopes and to the valves and servo-motors are all open to the atmosphere.

When the cock is turned to the "spin gyro" position, the cam which is attached to the handle of the cock depresses the piston valve sufficiently to permit the entry of the compressed air into the central cone of the cock, and thence via the exit port A to the spinning jets of the gyroscopes. It will be noted that in this position, the valves and servo-motors are still open to the atmosphere through the ports B and C.

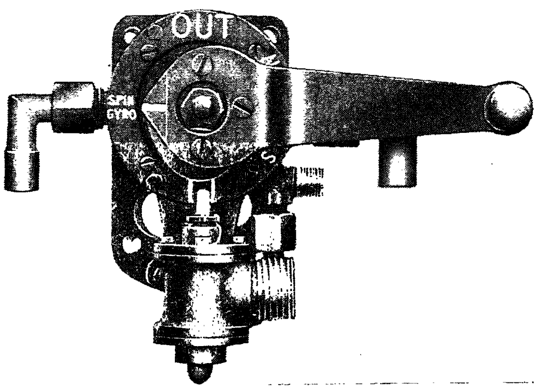


Fig. 26.—Main control cock in the "spin gyro" position

On turning the cock to the "in" position, the piston which had been depressed by the cam in the "spin gyro" position, is held down by the pressure of the compressed air on its top surface. In this position of the cock the compressed air is not only supplied to the gyro spinning jets, but also to the valves and servo-motors.

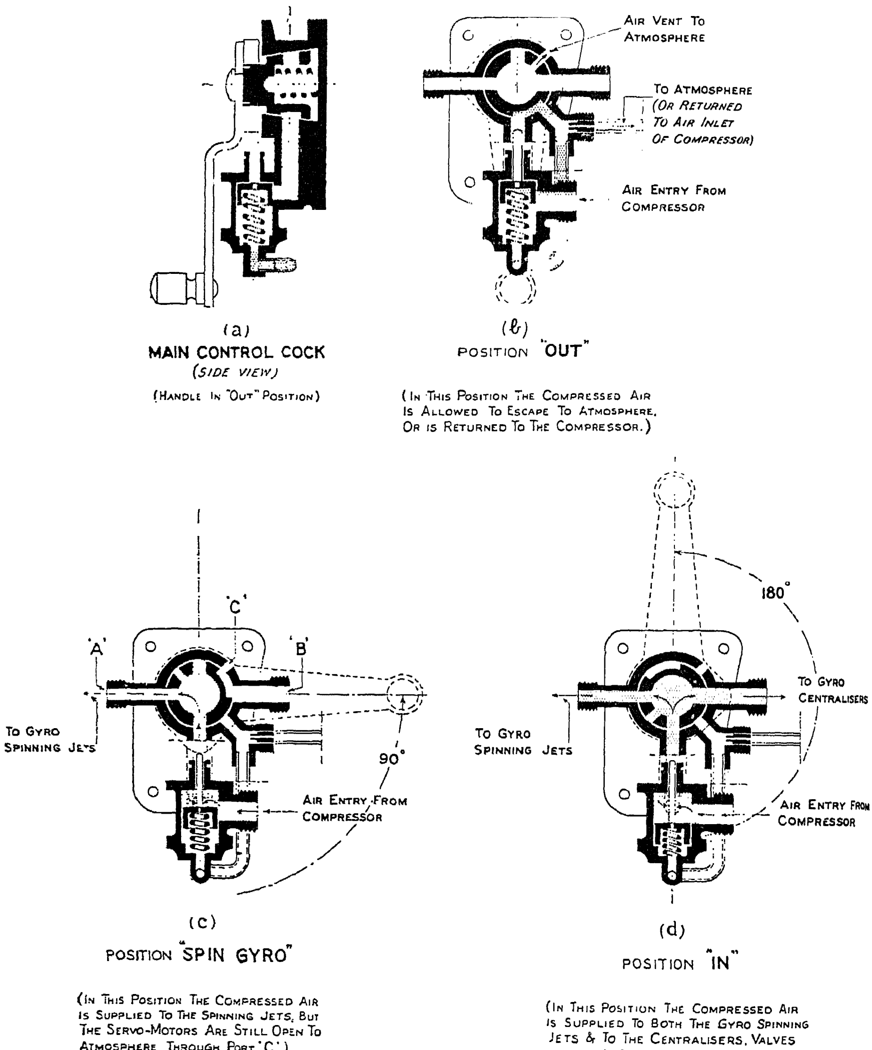


Fig. 27.—MAIN CONTROL COCK

While the above description covers the normal operation of the cock, its action under abnormal conditions of use must now be explained. Consider, therefore, an installation where a windmill-driven compressor is fitted, and suppose that the pilot accidentally commences to take-off with the main control cock in the "IN" position. Initially there is no pressure in the compressed-air system, since the compressor starts to

work only when the aircraft is travelling forward at considerable speed. Thus, since the safety piston on the main control cock is at its topmost position, the compressed air, as its pressure builds up, is prevented by the piston from gaining access to the gyros and servo-motors. Not until the handle of the cock is turned to the "SPIN GYRO" position, and the safety piston thereby depressed, can the compressed air gain access to the gyroscopes. Once the piston has been depressed it will remain down on account of the air pressure on its top surface, and after an interval of 5 minutes the cock may be turned to the "IN" position in the normal way. Thus, in the case of windmill-driven compressor installations, the safety piston provides a complete safeguard against the risk of taking off with compressed air applied to the servo-motors.

Course-change Cocks

Two types of cock for changing the course of the aircraft are available, namely:

(1) Mark IA (flat turn type).

(2) Type II (banked or flat turn).

The Mark IA cock has four positions: "STRAIGHT," "PORT," "STARBOARD," and "OBSERVER." In the "PORT" and "STARBOARD" positions compressed air is admitted to a small cylinder on the rudder-control unit which, by precessing the gyroscope, causes the aircraft to turn. (This is explained in detail under "Description of the Rudder Control and its Method of Operation.") The rate of turning with the Mark IA cock is set by the makers to between 40° and 100° per minute, according to the particular aircraft to which it is fitted.

When the cock is turned to the "OBSERVER" position the compressed air is supplied to the azimuth control cock (*q.v.*), and the control of turning is thereby transferred to the observer.

With the Mark IA cock, only flat turns can be carried out under automatic control, but since it is sometimes desirable to be able to perform banked turns, the type II cock has been introduced. By means of this cock the aileron control can be cut out of action, and during a turn the pilot himself controls the ailerons, while the rudder and elevator units maintain control of the turning and the pitch attitude of the aircraft. With the type II cock, banked turns may be carried out at rates which may be as high as 120° per minute.

The type II course-change cock embodies two interlinked cocks, the lower of which has two positions, "HAND" and "AUTO." In the "HAND" position the aileron control is cut out of action and the pilot himself controls the ailerons, while allowing the automatic pilot to make the required turn by turning the top cock to "PORT" or "STARBOARD" as required.

The top cock has three positions, "STRAIGHT," "PORT," and "STARBOARD," but the "PORT" and "STARBOARD" positions can be obtained

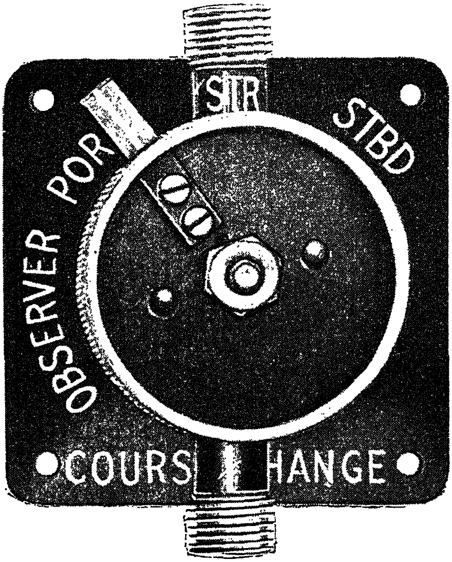


Fig. 28.—Course-change cock, Mk. IA

only when the lower cock is at "HAND." Similarly the lower cock can be returned to "AUTO" only when the top cock is at "STRAIGHT," thus preventing the pilot from re-engaging the automatic aileron control with the aircraft in a banked attitude.

With the top cock at "STRAIGHT" and the bottom one at "AUTO," slow flat turns can be carried out by means of the azimuth control cock.

Azimuth Control Cock

For all normal purposes, the fixed rate of turn which is provided by the course-change cock is sufficient when flying under automatic control, but for such special applications as photographic aerial surveys or for precision bombing it is usually desirable for a variable rate of turn to be available, and for this to be under the control of an observer or bomb-aimer.

The azimuth control cock is a two-way adjustable reducing valve, by means of which reduced air pressure may be applied to either side of the course-change cylinder on the rudder-control unit. By the use of this cock, an observer in any required position in the aircraft can control the precise heading of the aircraft. The azimuth control cock is sometimes fitted in the pilot's cockpit, particularly in civil aircraft, as its use enables course corrections of only a few degrees to be made with greater facility than by the use of the course-change cock.

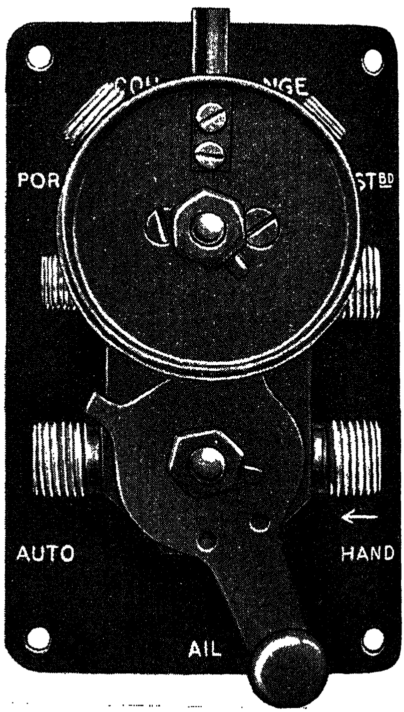


Fig. 29.—Course-change cock, type II

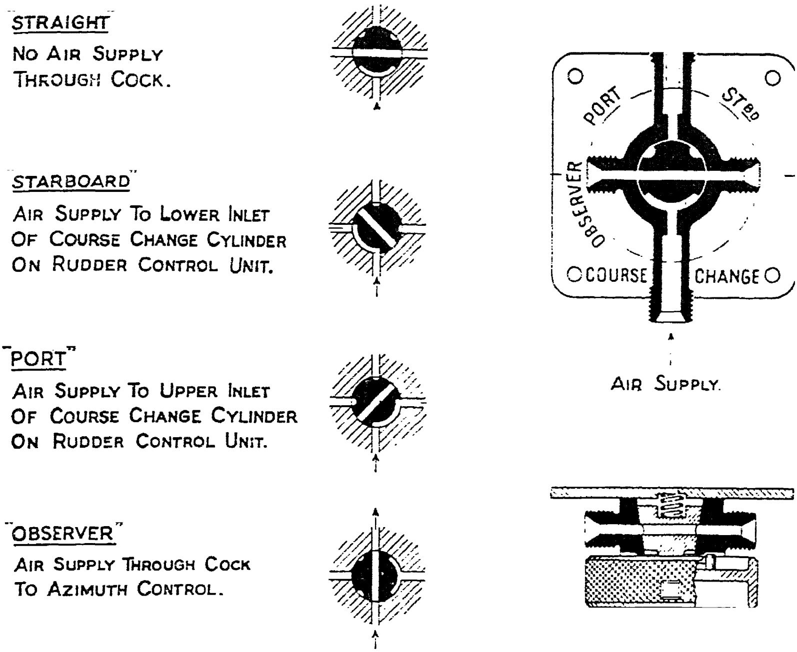


Fig. 30.—Course-change cock, Mk. IA, showing alternative positions

Pitch-control Lever

This is a Bowden lever operating an endless Bowden cable which is attached to the rudder-control unit. The lever moves over a dial plate marked in degrees, the zero on the dial representing level flight. By operating this lever in the same sense as the control column, the pilot can control the attitude of the aircraft between the limits of 5° climb to 10° dive while the automatic pilot is in use.

It may be remarked that since this control operates on the gyroscope itself, causing it to precess to a new datum, the transition of the aircraft attitude is smooth and gentle, even if the control lever is moved suddenly from one extreme position to the other.

Lateral-trim Lever

This is a similar lever to that of the pitch control, but in this case it operates on the aileron-control unit. The lever is provided with a dial plate marked "LEFT WING LOW" and "RIGHT WING LOW," and by operating the lever in the same sense as the control column, the pilot can

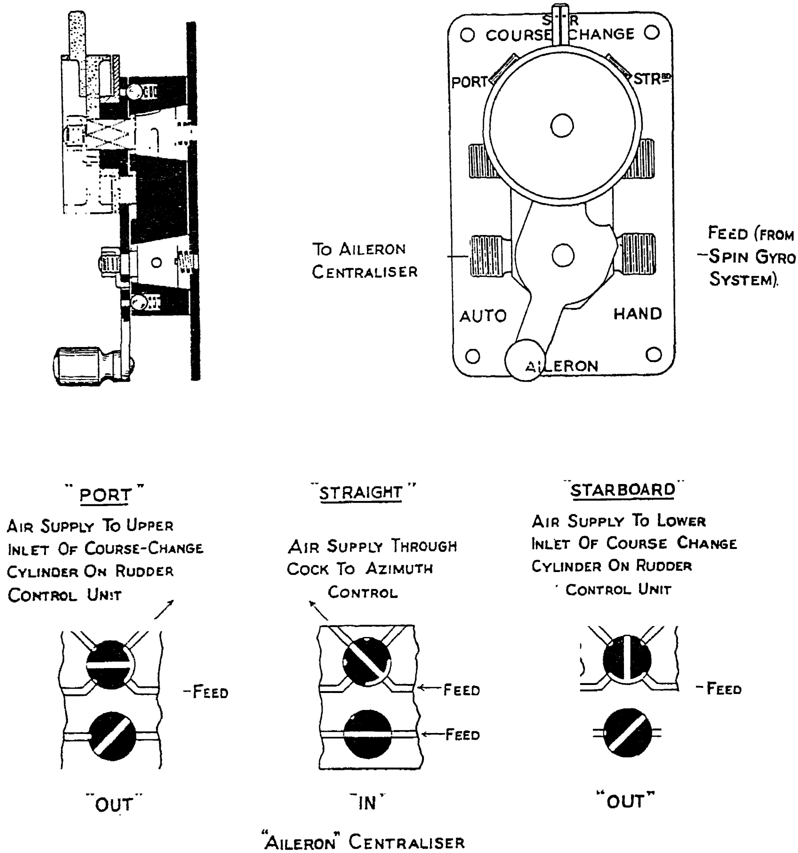


Fig. 31.—Course-change cock, type II, showing interior arrangement

make small corrections to the roll attitude and so allow for errors in trim due to imperfect rigging.

Safety Catches Lever

This lever controls three safety catches which provide a complete and instantaneous mechanical disconnection between the units of the automatic pilot and the aircraft controls for use in the case of an emergency, such as might arise, for example, in the event of damage to some vital part of the mechanism.

The lever has two positions, " IN " and " OUT," and it is provided with a ratchet to enable the catches to be left disengaged.

N.B.—If the automatic pilot is to be used on any given flight, the safety catches *must* be engaged *before* taking off by releasing the lever and moving the aircraft-control surfaces by means of the rudder bar and the control column through their *full* range to ensure proper engagement of the catches.

The safety catches should *always* be withdrawn before landing, but the main control cock *must* be turned to "OUT" before withdrawing the catches, to avoid damage to the gyroscopes.

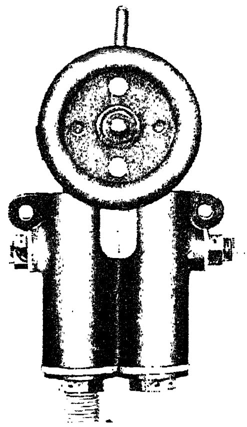


Fig. 32.—AZIMUTH CONTROL COCK

This enables variable rates of turn to be obtained.

Air-expansion Chamber

The two relay valves which form part of the elevator and aileron controls, and which will be described later, require a supply of compressed air at a somewhat lower pressure (about 20 lbs./sq. in.) than the main supply. In order to obtain this lower pressure, some

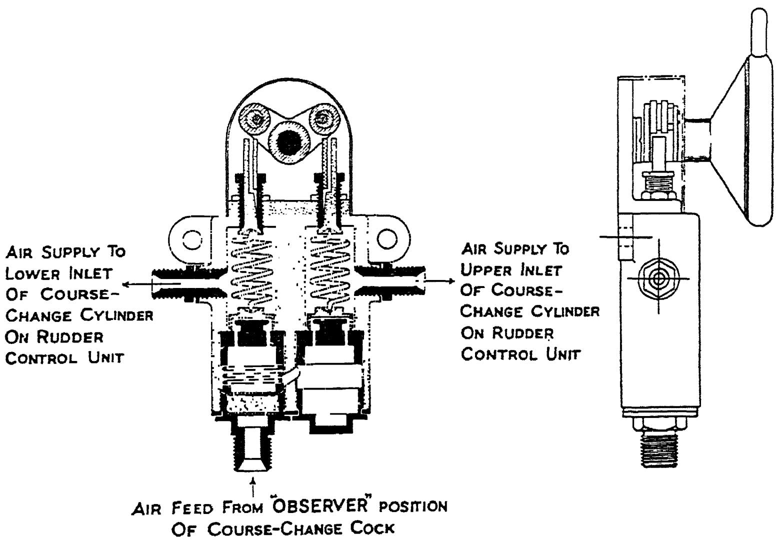


Fig. 33.—AZIMUTH CONTROL COCK

This consists essentially of a two-way adjustable reducing valve.

of the compressed air is allowed to expand through a small calibrated jet into the air-expansion chamber. The expanded air, being at a lower pressure, is then available for the relay valves.

The expansion jet is protected by a fine gauze filter in the inlet (central) connection, which should be inspected and cleaned periodically.

Any moisture which accumulates in the expansion chamber can be drained off by removing the drain plug which is situated at one side of the base of the chamber.

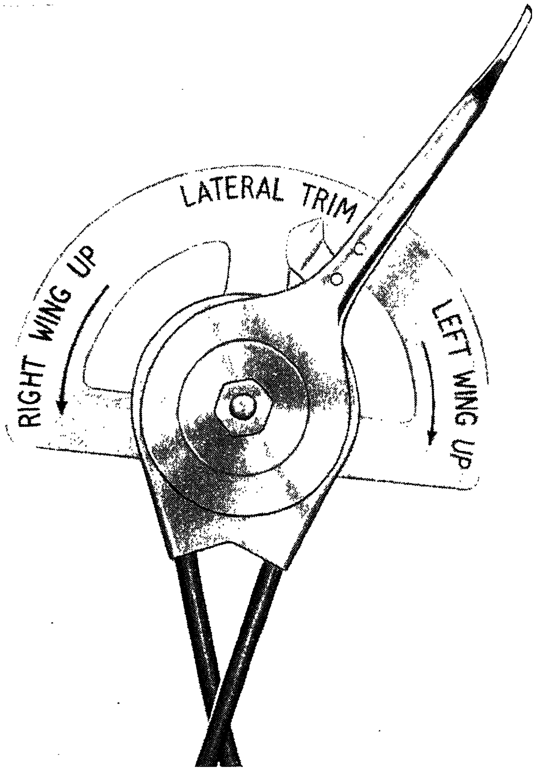


Fig. 35.—Lateral-trim lever

Automatic Cut-out

When an aircraft is flying at high speed it is evident that serious strains might be imposed on the structure of the aircraft in the event of a sudden and large application of the elevators. Under normal circumstances such a condition will never arise, since

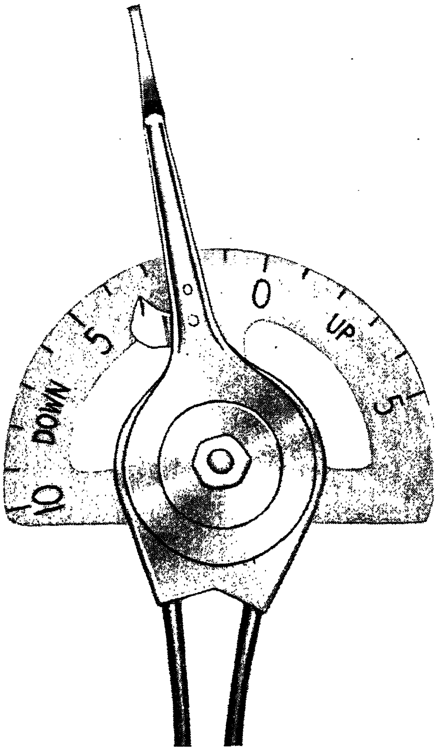


Fig. 34 (*left*).—Pitch-control lever

the control-surface movements with the Smith automatic pilot are very small, even under exceedingly rough weather conditions. It is just conceivable, however, that dangerously large elevator movements might arise due to some accidental and excessive pitching oscillation, or even to some defect in the gyroscopic mechanism, and to guard against the consequences of such an event the automatic cut-out has been developed to disconnect the automatic pilot instantaneously in the event of an excessive movement of the elevators.

The automatic cut-out consists of two distinct units, the cut-out itself and the quick release unit. The cut-out unit is installed on and operated by the elevator servo-motor, and it is normally set to permit an elevator movement of $\pm$ 5° from the datum position before coming into action. The datum position is adjustable according to the trim of the aircraft. In the event of an elevator movement in excess of the specified limit, the cut-out operates, and breaks an electrical

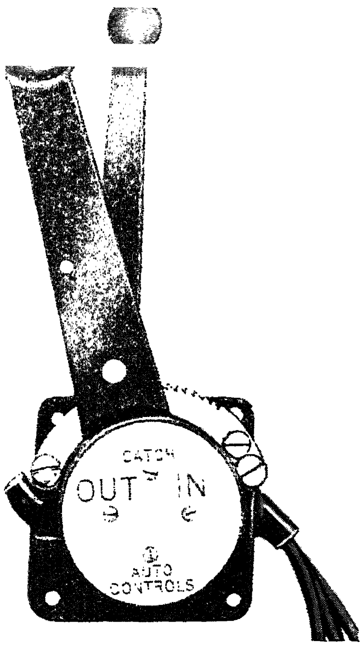


Fig. 36.—SAFETY CATCHES LEVER

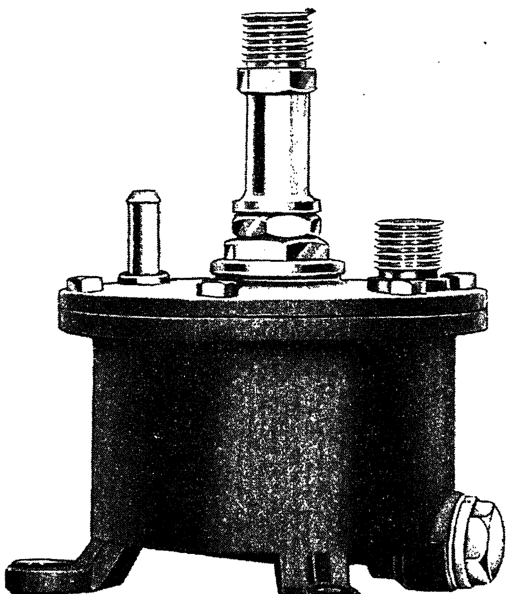


Fig. 37 (*left*).—AIR-EXPANSION CHAMBER

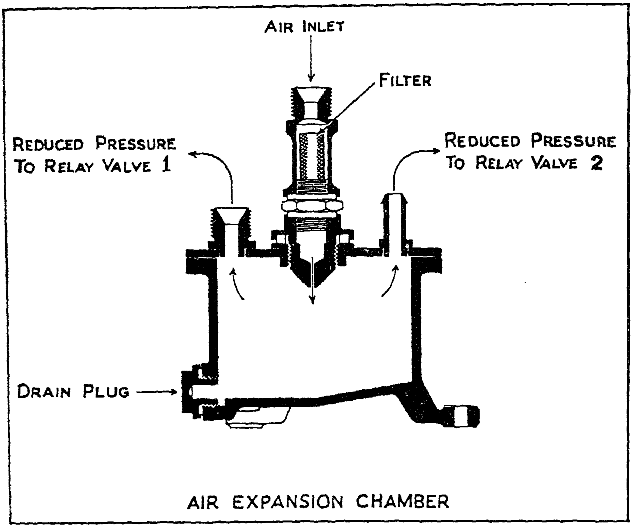


Fig. 38.—INTERIOR OF AIR-EXPANSION CHAMBER

circuit to the quick release unit.

The quick release unit consists of an electrical relay and an air-valve system. When the electrical circuit through the cut-out is complete and the compressed-air pressure is normal the automatic pilot functions in its normal manner, but when the electrical circuit is broken by the operation of the cut-out, the relay of the quick release unit is de-energised, causing the air-valve system to operate and divert the compressed-air supply for the gyroscopes and servo-motors to atmosphere, thus cutting out the automatic pilot. The aircraft controls are thus instantly freed for manual control.

As will be evident from the detailed description which follows, the datum position of the cut-out should be reset by pressing the resetting switch whenever the pitch attitude of the aircraft is changed when flying under automatic control. If this is not done, it is possible that the cut-out will be in such a position that it will tolerate, for example, an upward movement of the elevators of 8° and a downward movement of only 2°. In these circumstances the cut-out and quick release units are likely to operate during normal use.

In the event of the cut-out operating, the normal procedure is for the pilot immediately to turn the main control cock to "SPIN GYRO," press the resetting switch to reset the datum of the cut-out, and re-engage the automatic pilot by turning the main control cock back to "IN."

Cut-out Unit (Detailed Description)

Referring to Fig. 42, which illustrates the operation of the cut-out unit, it should be noted that this illustration is diagrammatic only and does not accurately represent the actual form of construction adopted.

The cut-out unit is mounted on the elevator plate as shown in Fig. 40. The spindle A (Fig. 42) is geared by means of a toothed quadrant with the moving arm of the elevator plate, and hence with the piston of the

elevator servo-motor. Every angular position of spindle A therefore corresponds with a definite position of the aircraft elevators. Forming an integral part of spindle A is the disc B, and between the disc B and the armature C is a disc of insulating material D which carries a contact segment E. The disc D is sandwiched between the disc B and the armature C by the pressure of the spring F, and in normal operation all these components move together with the spindle A.

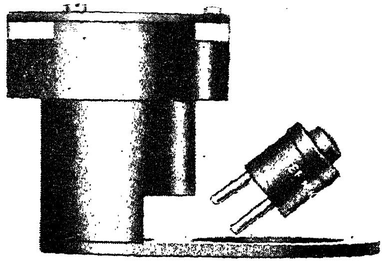


Fig. 39.—AUTOMATIC CUT-OUT

An extension piece G on the disc D lies between the ends of a coiled

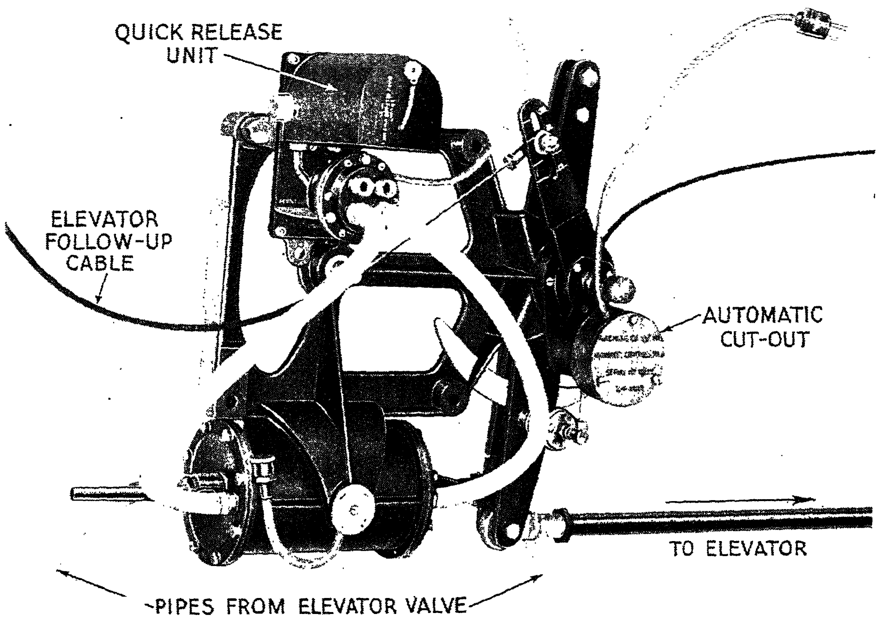


Fig. 40.—AUTOMATIC CUT-OUT AND QUICK RELEASE UNITS, MOUNTED ON THE ELEVATOR PLATE

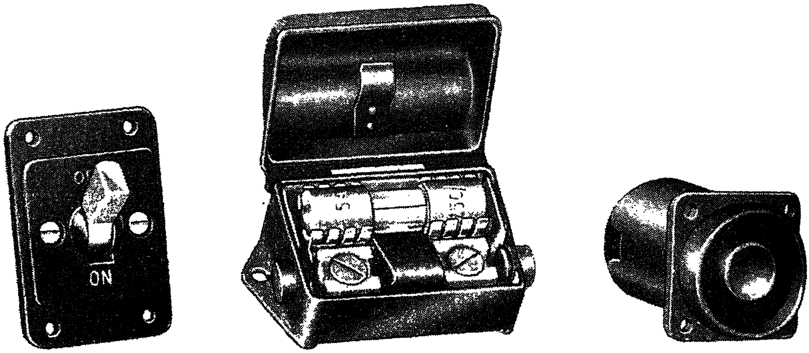


Fig. 41.—Automatic cut-out switch, fuse box, and resetting switch

spring H, and a stop J is also adjacent to the ends of the spring H. A rotation of the disc D in either direction thus stores energy in the spring H, one end of the spring being carried round while the other is held by the stop J. If D is rotated and then released, it will therefore return to its neutral position under the action of the spring H.

The disc D carries a contact segment E through which the two adjustable contacts KK complete the electrical circuit, and when the disc D is in the "neutral" or central position, the contacts KK are equally spaced in relation to the segment E.

The base of the instrument contains an electro-magnet M, the poles of which are adjacent to the armature C. When this magnet is energised by pressing the resetting switch, the armature C is attracted, and the disc D (which is normally held fast between the disc B and the armature C) is released. It is thus enabled to return to its neutral position under the action of the spring H.

The positions of the contacts KK are generally set so that they will permit a movement of the elevators of 5° in either direction from the mean position before the circuit through the contact segment E is broken, but since any alteration in the pitch attitude of the aircraft must involve a change in the mean position of the elevators, and hence in the mean position of spindle A, it is evident that the resetting switch must be pressed whenever the pitch attitude is altered, in order that the neutral or central position of disc D may still correspond with the new mean position of the elevators. Any movement of the elevators in excess of 5° from the mean position will then cause the circuit through the contacts KK and the segment E to be broken.

Quick Release Unit

It is this unit which performs the actual operation of releasing the aircraft controls from the automatic pilot in response to the direction of the cut-out unit. Referring to Fig. 44, which is diagrammatic only, the electro-magnet or relay A controls the operation of a small air valve B. In normal use, the magnet is energised (by current flowing through the contacts KK of the cut-out unit), and the piston of the air valve B is in the position shown. Compressed air is admitted to the chamber C, compressing the spring-loaded bellows and sealing off the ports DD which are connected with the compressed-air pipes leading to the elevator servo-motor and gyro centralisers.

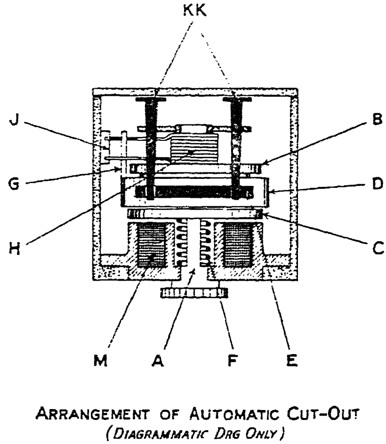


Fig. 42.—INTERIOR OF AUTOMATIC CUT-OUT

If the electrical circuit is broken by the operation of the cut-out, relay A is de-energised, the piston of valve B is raised, thus shutting off the compressed air and allowing the bellows to expand. This action uncovers the ports DD and allows the air pressure in the pipes leading to the elevator servo-motor and centralisers to fall to atmospheric pressure, thus instantly releasing the aircraft from the control of the automatic pilot and allowing the pilot to resume manual control.

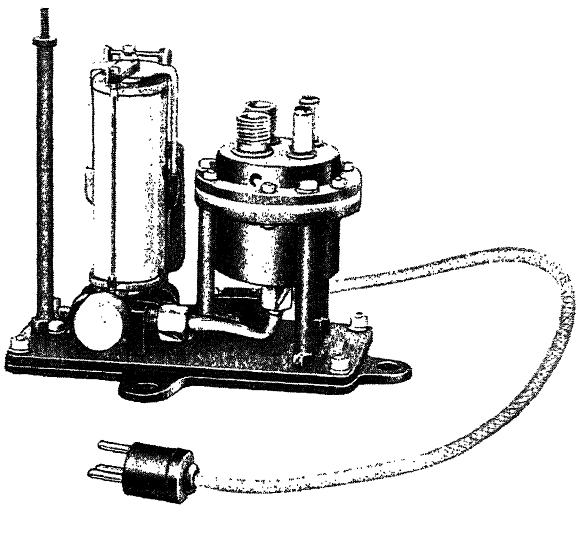


Fig. 43.—QUICK RELEASE UNIT

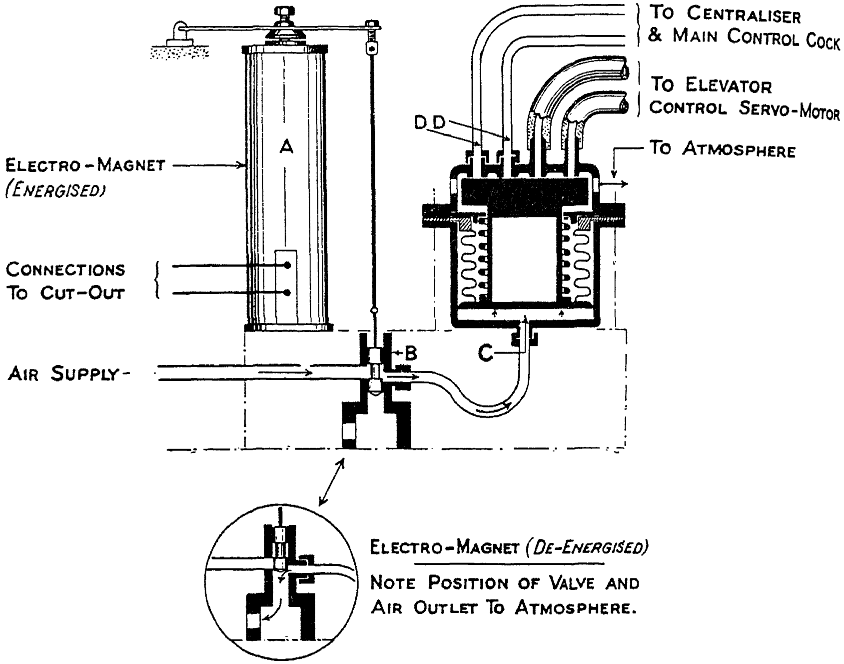


Fig. 44.—Arrangement of quick release unit

The electrical connections of the cut-out and quick release units are as shown in Fig. 45. On pressing the resetting switch, two circuits are completed ; one being through the resetting magnet (M, Fig. 42) of the cut-out, and the other through the relay A of the quick release unit. Once the latter has become energised, it is held " on " by the self-locking contacts which form part of the relay.

The units then function as described above until the breaking of the circuit by the contact segment of the cut-out releases the relay of the quick release unit and thus effects the release of the aircraft controls from the automatic pilot.

A switch is provided to short-circuit the contacts of the cut-out in order to render it non-operative when so desired.

Turn Regulator

Certain types of modern aircraft are only capable of executing flat turns at very low rates of turn. The Smith automatic pilot is specifically designed to maintain the aircraft level laterally under all conditions.

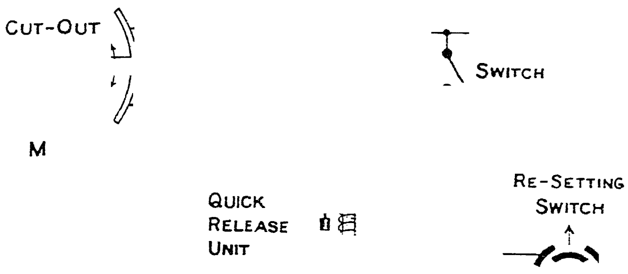


Fig. 45.—ELECTRICAL CIRCUIT OF AUTOMATIC CUT-OUT

It follows that such aircraft are only able to turn slowly under the control of the automatic pilot, although faster turns can, of course, be executed by such aircraft under automatic control if the aileron control is cut out of action by the use of the type II course-change cock, as described on page 53.

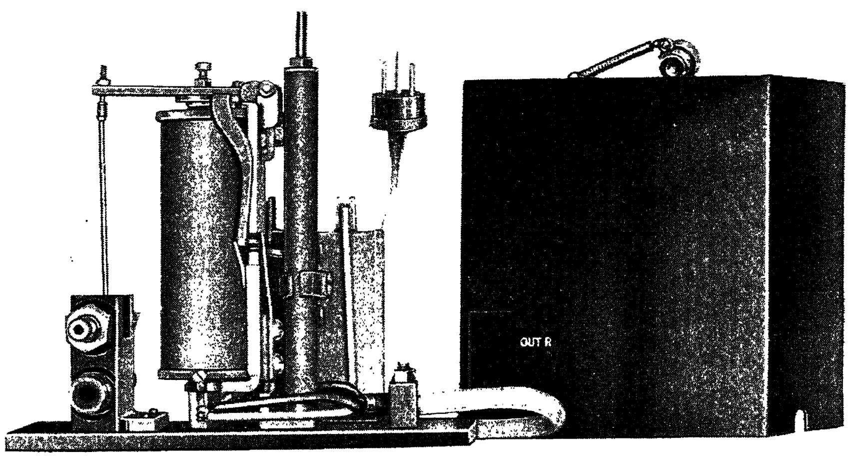


Fig. 46.—TURN REGULATOR

As will be described later, turning of the aircraft is effected by precessing the rudder gyroscope itself, and in the case of a slow-turning aircraft it is possible that it may not be able to turn as fast as the gyroscope is precessed. It is important that the aircraft should "keep pace" with the gyroscope and so, to prevent the gyroscope precessing at a rate faster than the aircraft can turn, a turn regulator is fitted in the case of slow-turning aircraft.

The unit is operated by a pair of electrical contacts which are fitted on either side of the outer gimbal ring of the rudder gyroscope. A small degree of movement of the outer gimbal ring in relation to the gyro framework (such as occurs if the aircraft does not keep pace with the gyroscope) breaks a circuit through an electro-magnetic relay which, by means of a small air valve, causes the compressed-air supply to the gyroscope precessing cylinder to be interrupted. Further precession of the gyroscope is therefore prevented until the aircraft has "caught-up" with the gyroscope. When the outer gimbal ring and the gyro framework have once more resumed their normal relative positions, the circuit is completed again automatically and the precession of the gyroscope is continued.

DESCRIPTION OF THE RUDDER CONTROL AND ITS METHOD OF OPERATION

As explained previously, a gyroscope tends to maintain the direction of its axis fixed in space, and if a freely supported gyroscope, spinning at high speed, is carried in an aircraft, the axis remains pointing accurately in one direction over long periods, no matter how the aircraft may manœuvre. Suppose the aeroplane is flying on some given course, and suppose that some atmospheric disturbance causes it to deviate by a few degrees from its course. Since the axis of the gyroscope will not have been deflected, the exact departure of the aircraft from its course could be readily ascertained by reference to the gyroscope. The gyroscope, in fact, acts as a detector of any deviation of the aircraft, and provides the datum to which the aircraft must be returned.

The actual gyroscope employed in the rudder control was illustrated in Fig. 6, and a view of the complete rudder (and elevator) control is shown in Fig. 48. From this figure it will be seen that the gyro rotor A is supported in ball bearings by the inner gimbal ring B which, in turn is carried by horizontal pivots in the outer gimbal ring C. The outer gimbal ring is supported by pivots at the top and bottom which give it freedom about the vertical axis. It is very important that these various pivots should be as free from mechanical friction as possible.

Compressed-air Supply

The compressed-air supply for rotating the gyro rotor is supplied direct from the main control cock to the bottom pivot of the outer gimbal

ring. This pivot is hollow, and the air is thence conducted to the two spinning jets which are situated close to the horizontal pivots, by a small pipe which is embedded in the surface of the outer ring. The spinning jets direct the air into small Pelton-like buckets which are cut in the periphery of the rotor.

Adjustment of Rotor Bearings

The gyro rotor should spin at a speed of approximately 11,000 r.p.m. under the air pressure of 35 lbs./sq. in. The adjustment of the rotor bearings is important, and while it must be such that no shake whatever can be felt, the bearings must not be so tight that they cause excessive friction, since in such a case the gyroscope will not be capable of attaining its correct speed. The adjustment should be such that the rotor will just commence to rotate under an air pressure of 4 lbs./sq. in. Great care must be exercised in adjusting the bearings by taking up the end play should it ever become necessary, and it is strongly recommended that this should only be undertaken by the makers.

The Rudder Valve

Bearing in mind the directional stability of the gyroscope, and its freedom of movement about the vertical axis of the outer gimbal ring, it will be evident that any deviation of the aircraft from its course will result in a relative movement about the vertical axis between the outer gimbal ring of the gyroscope and the supporting framework. Any such motion is detected by a small valve D, known as the rudder valve, the casing of which is attached to the supporting framework and the piston of which is attached by the link F to a point on the top of the outer gimbal ring. The rudder valve is constructed with extreme care, and the slightest motion in one direction or the other between the valve casing and its piston is sufficient to cause the admission of compressed air to one side or the other of the rudder servo-motor G.

The Servo-Motor

The servo-motor consists of a double-acting cylinder and piston, the piston rod of which is connected to the dummy rudder bar H, from the end of which a rod is connected to the aircraft rudder controls. It will be noticed that the servo-motor piston rod is actually connected to a lever which is pivoted about the same centre as the dummy rudder bar. This lever is capable of moving independently between the top and bottom members of the dummy rudder bar, but under normal circumstances it moves as one unit with the rudder bar, being locked with it by the safety-catch device J (Fig. 50), which is operated from the pilot's cockpit (see page 56). The purpose of this arrangement is to provide a complete mechanical disconnection between the servo-motor and the aircraft rudder for use in the case of an emergency. Similar safety catches are

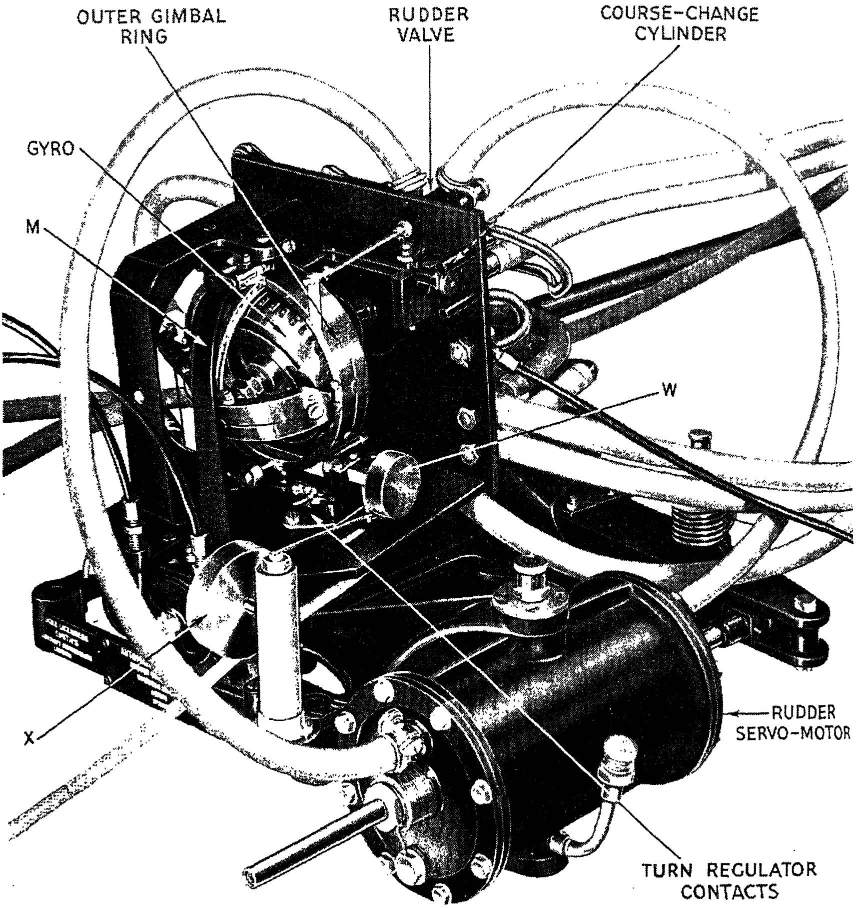


Fig. 47.—Rudder control unit

Showing the contacts of the turn regulator just beneath the gyroscope.

provided for the elevators and ailerons, and all three are operated simultaneously by the safety catches lever in the pilot's cockpit.

" Follow-up " System

Returning to the gyroscope, it was explained above that when the aircraft deviates from its course the relative motion between the

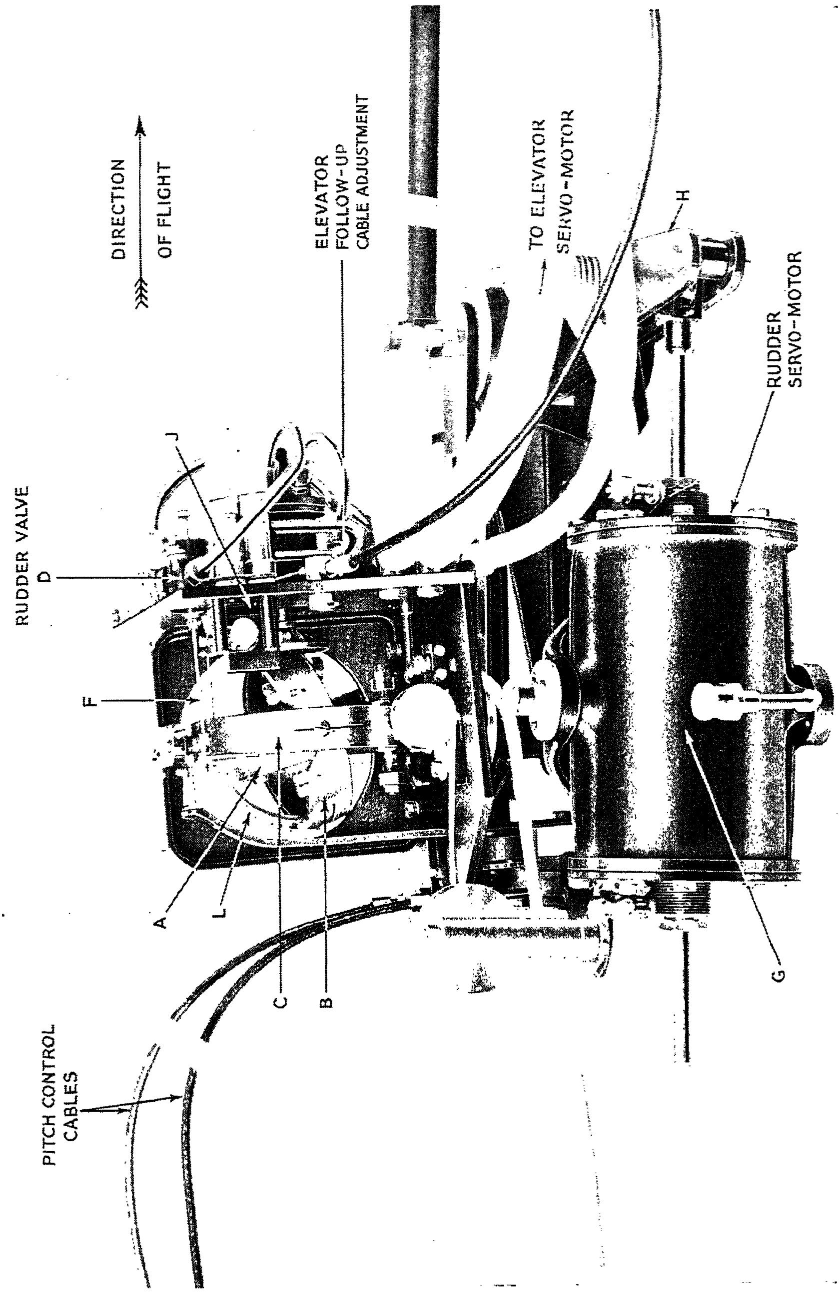
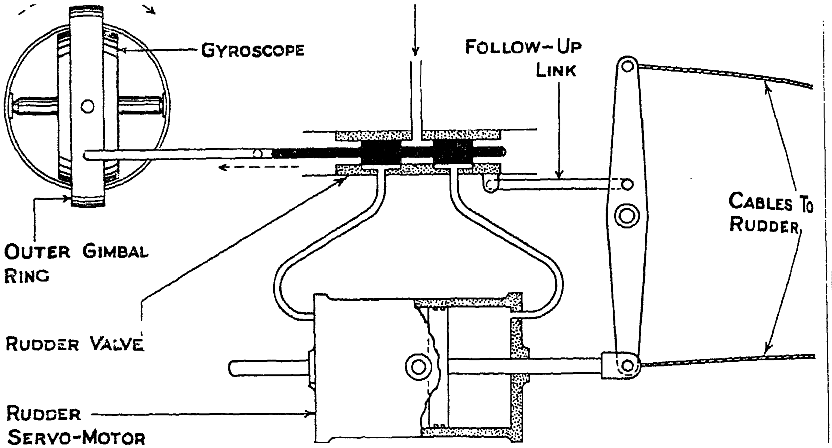


Fig. 48.—Rudder and Elevator Control Unit from Right-hand Side, showing Rudder Control Mechanism



DIAGRAMMATIC PLAN VIEW OF RUDDER CONTROL SYSTEM

Fig. 49.—DIAGRAMMATIC ARRANGEMENT OF RUDDER CONTROL AND FOLLOW-UP MECHANISM

supporting framework and the gyroscope itself causes the rudder valve D to operate and admit compressed air to one side or the other of the servo-motor G. It will be clear, however, that unless some means were adopted to control the movement of the servo-motor, the piston would travel to the extremity of its stroke, and thus apply the full amount of the aircraft rudder, irrespective of the amount by which the aircraft had departed from its intended course. A control which applied full rudder angle for even the smallest departure of the aircraft from its course would obviously be impractical, and in order to achieve the smooth operation of the control, it is necessary to arrange that the application of the aircraft rudder is proportional to the angle through which the aircraft has departed from its course. Furthermore, as the aircraft returns to its course, the rudder angle must be progressively reduced.

This requirement is satisfied by the incorporation of a "follow-up" system, by the action of which the movement of the servo-motor piston causes the casting of the rudder valve to "follow" the apparent movement of its piston. This action, which will be made more clear by the following description, results in the travel of the servo-motor piston being limited to an amount determined by the apparent movement of the rudder valve piston.

Referring to Fig. 49, which is diagrammatic only, it is clear that the

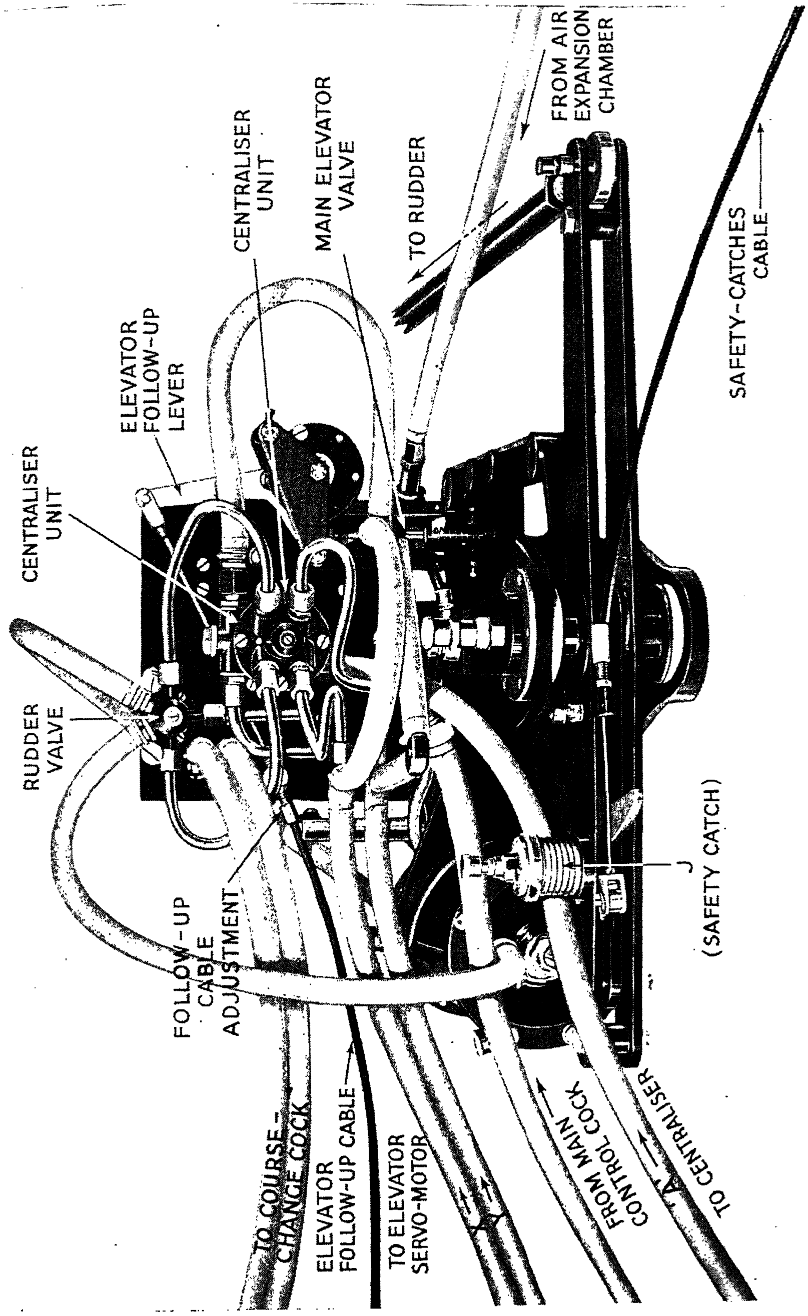
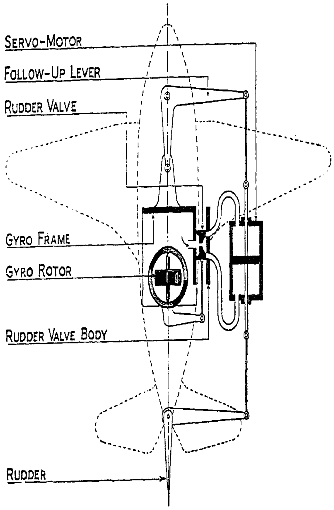
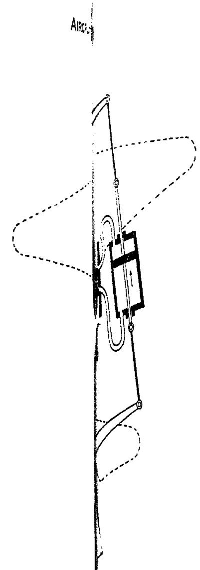


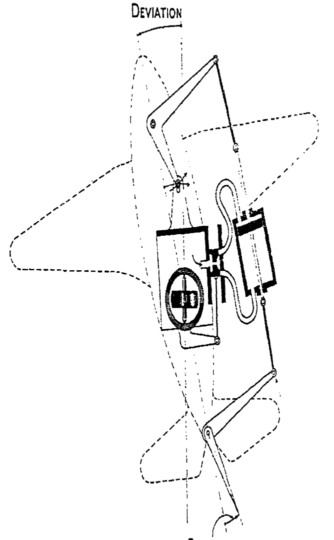
Fig. 50.—Rudder and Elevator Unit from the Front, showing the Centraliser Unit and Disposition of the Connecting Pipes



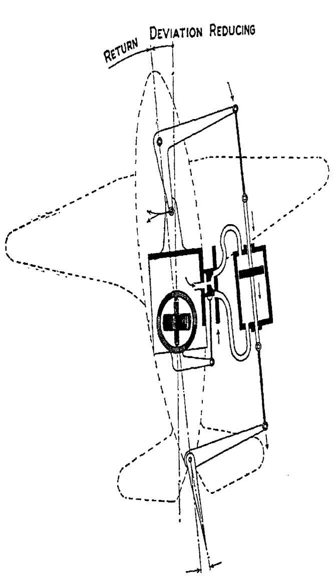
A. In this figure, the aircraft is shown flying steadily on its course with the Rudder Valve, Servo-Motor and Follow-up System in the normal positions.



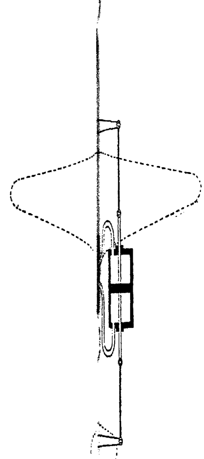
B. The aircraft is here ... disturbed from its true course. The Rudder Valve has ... Servo-Motor which has begun to apply a correcting ... the same time, the Follow-up System has begun to ... Valve.



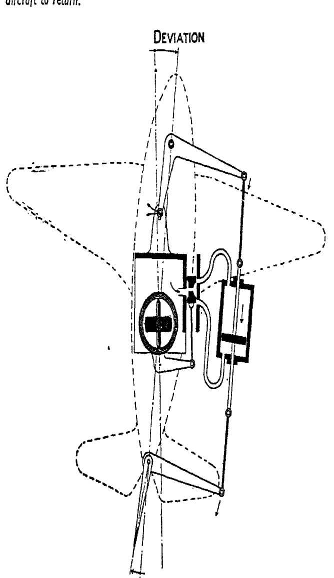
C. The aircraft is here supposed to have reached the limit of its departure off course and, in an instant, it will commence to return to its course. Since it is not turning, the Rudder Valve is here closed, no further application of rudder is taking place, but the rudder which has been applied during the deviation will now cause the aircraft to return.



D. The aircraft is now returning to its course, and the Rudder Valve is admitting compressed air to the opposite end of the Servo-Motor, causing the applied rudder to be progressively reduced.



E. The aircraft has now ... course, and the Rudder Valve, Servo-Motor, and aircraft ...



F. In returning to its course, the aircraft may "over-shoot" a little. To correct this, the Rudder Valve and Servo-Motor will apply rudder in the opposite direction.

Fig. 51.—Diagrams showing the operat... control mechanism and follow-up system

relative motion which must occur between the gyroscope and the aircraft when it deviates from its course will result in a partial opening of the rudder valve. The compressed air which is thereby admitted to one side of the servo-motor causes its piston to travel and operate the rudder bar. It will be noticed, however, that the rudder bar is connected by a link to the casing of the rudder valve. The effect of this connection is to produce a movement of the casing of the rudder valve in such a direction as to reclose the valve and hence to prevent further travel of the servo-motor piston.

An Example

Suppose, for example, that the aircraft has deviated to port. Such a deviation may, for the moment, be regarded as a deviation of the gyroscope in the opposite direction, i.e. in a clockwise direction as shown by the dotted arrow in Fig. 49 (although in actual fact, of course, it is the gyroscope which remains stationary and all the rest of the associated gear which moves with the aircraft). Whichever way the deviation is regarded, it is clear that the result will be a leftwards movement of the piston of the rudder valve relatively to its casing. Compressed air will thereby be admitted to the left-hand side of the servo-motor, the rudder bar will move as shown by the arrows, and the casing of the rudder valve will be moved by the "follow-up" link so as to "chase" the apparent movement of its piston. The valve is thereby closed, and further motion of the servo-motor is prevented. Thus, the actual travel of the servo-motor and the application of the aircraft rudder is made directly proportional to the amount by which the aircraft has departed from its course.

Supporting Framework

Returning to the actual equipment as shown in Fig. 48, the whole supporting framework is not rigidly attached to the base casting as has hitherto been supposed, but is supported in a bearing situated beneath the gyroscope which permits rotation of the framework about the vertical axis. The framework is connected to the rudder bar through a pair of levers (which may be more clearly seen at KK in Fig. 57), and when the rudder bar moves, the whole framework (together with the rudder valve casing) is rotated slightly about its vertical axis.

How Rudder Angle is Controlled

Suppose that the aircraft has received a disturbance and in consequence has departed from its course. The gyroscope and gimbal rings remain directionally fixed and relative movement will occur between the gyroscope and the supporting framework. This will cause the rudder valve to operate and, in consequence, compressed air will be admitted to one side of the rudder servo-motor. The resulting movement of the

rudder bar will apply the necessary correcting movement to the aircraft rudder. As the rudder bar moves, however, the ratio levers KK (Fig. 57) cause the supporting framework of the gyroscope to rotate slightly in the same direction as the apparent displacement of the rudder-valve piston. The rudder valve is thereby closed and, in consequence, no further movement of the servo-motor piston and no further application of rudder takes place.

In consequence of the application of the aircraft rudder, the aircraft will commence to return to its course, and, as it commences to return, the rudder-valve piston will be displaced relatively to its casing in a direction opposite to that in which it was displaced at the origin of the disturbance. As before, the servo-motor will be operated by the opening of the rudder valve, only this time it will move in the opposite direction so as to reduce the rudder angle originally applied. In this way the application of rudder angle is progressively reduced as the aircraft returns to its correct course. In fact, the whole function of the "follow-up" principle is to ensure that at all times the degree of applied rudder is proportional to the amount by which the aircraft is off its course.

In Fig. 57 it will be seen that the two levers KK are slotted and connected together by the adjustable pin L. One of these levers is connected to the rudder bar, while the other is attached to the framework of the gyroscope, and, as the rudder bar is moved by the operation of the servo-motor, the linkage of the two levers by the pin L causes the gyro framework to make a small rotary movement in its bearing beneath the gyroscope. By adjusting the position of the pin L, one is enabled to adjust the effective ratio between movements of the rudder bar and the "follow-up" movements of the gyro framework, and a means is thus provided for adjusting the magnitude of rudder correction applied for a given deviation. The correct adjustment of the follow-up ratio varies with different types of aircraft, but once it has been correctly set, it will require no further adjustment.

Centraliser

Except when the gyroscope is actually controlling the movements of the aircraft, it must be securely clamped to its framework. This action is performed by a unit known as the centraliser which, as may be seen in Fig. 52, comprises a cylinder with a spring-loaded piston and cone. The cone of the centraliser engages with a pin on the inner gimbal ring and, except when the gyroscope is actually in control of the aircraft, the cone is kept engaged with the pin by means of the spring S. When the main control cock is turned to "IN," however, compressed air is supplied to the centraliser cylinder through the pipe A (Fig. 50), the spring S is compressed, and the cone is withdrawn from the gyroscope.

The gyroscope is thus released and, as the centraliser piston with-

draws, it uncovers a port midway in the cylinder through which the compressed air is supplied to the various valves and servo-motors. The control of the aircraft is thereby transferred to the automatic pilot.

A further function of the centraliser is to exhaust the compressed air from the servo-motors when the automatic pilot is not in use, and thus to ensure that the free movement of the aircraft controls by the pilot is not impeded when the aircraft is under manual control. It will be observed in Figs 50 and 52 that there are four pipe unions on the end of the centraliser unit and, as may be seen in Fig. 52, these unions are all open to the atmosphere when the centraliser cone is in engagement with the gyroscope, but when the cone is withdrawn from the gyroscope the piston of the centraliser seals off the four orifices. These four orifices are connected by pipes, which may be seen in Fig. 50, to the two sides of the rudder and elevator servo-motors respectively, and so long, therefore, as the main control cock remains in the "OUT" or "SPIN GYRO" positions, only atmospheric pressure can exist in the servo-motors. On turning the main control cock to "IN," however, these exhausting pipes are all sealed off as described above, and the air pressures in the servo-motors are then controlled by the rudder and elevator valves.

Change of Course

There are two possible methods of altering course on a gyroscopically controlled aircraft. The first is to change the relative positions of the gyroscope and the aircraft. The second method which has been adopted in the Smith automatic pilot consists in precessing the gyroscope itself. Since the aircraft is controlled by the position of the gyroscope, it automatically changes course as the gyroscope precesses.

From the brief description of gyroscope theory beginning on page 34, it will be recalled that in order to precess a gyroscope about the vertical axis, a torque must be applied about a horizontal axis at right angles to the axis of the rotor. This torque is actually applied to the inner gimbal ring of the gyroscope by means of a small double-acting air cylinder known as the course-change cylinder, which may be seen at J, Fig. 48, just beneath the rudder valve. The piston of the course-change cylinder is connected to the inner gimbal ring by means of a link and a quadrant-shaped arm L.

Compressed air can be admitted to either side of the course-change cylinder by the operation of the course-change cock in the pilot's cockpit, and the resulting thrust on the piston applies a torque about the horizontal axis of the inner gimbal ring and so causes the gyroscope to precess in azimuth. Since the course maintained by the aircraft is controlled by the position of the gyroscope, it follows that the aircraft will turn as the gyroscope itself is precessed.

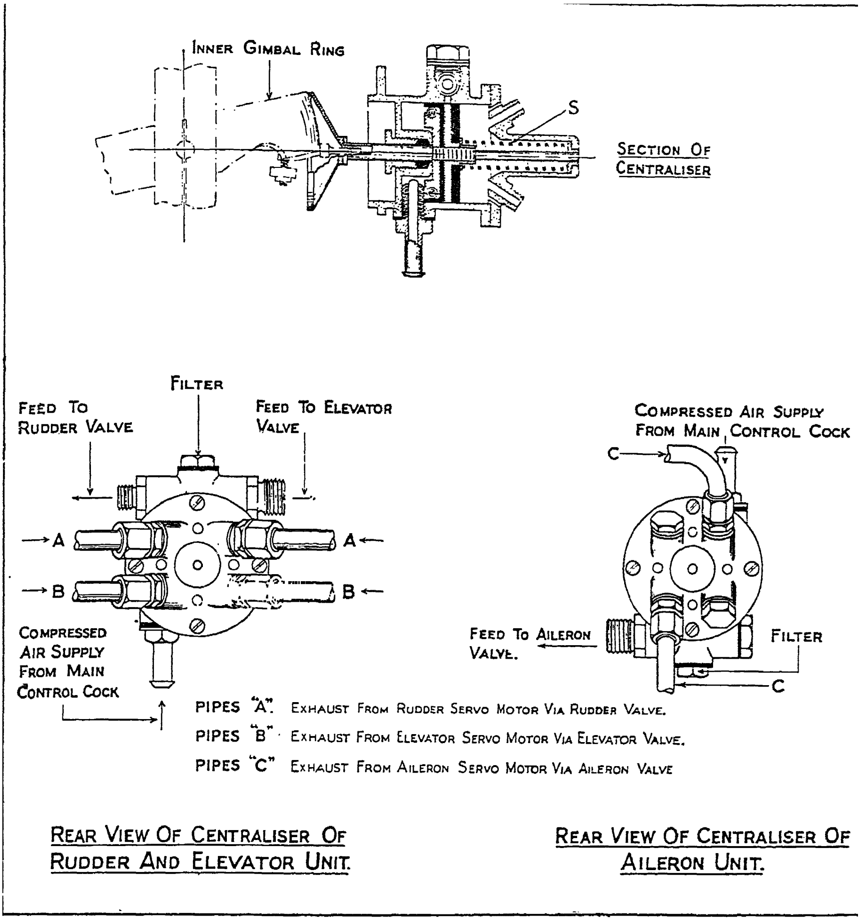


Fig. 52.—THE INTERIOR CONSTRUCTION AND ARRANGEMENT OF THE CENTRALISER UNITS

Latitude Adjustment Weight

As was explained previously, a gyroscope can only be balanced to have zero rate of azimuth precession in one given latitude, and if the same gyroscope is removed to another latitude without rebalancing, it is no longer able to provide an accurate directional indication. The magnitude of the error introduced by using a gyroscope in some latitude other than that for which it has been balanced is not a large one, and, in fact, a gyroscope balanced for use at the Equator will only precess at the rate of 15° per hour if used at the North or South Poles. But an error of the same order would arise between North Temperate and South Temperate

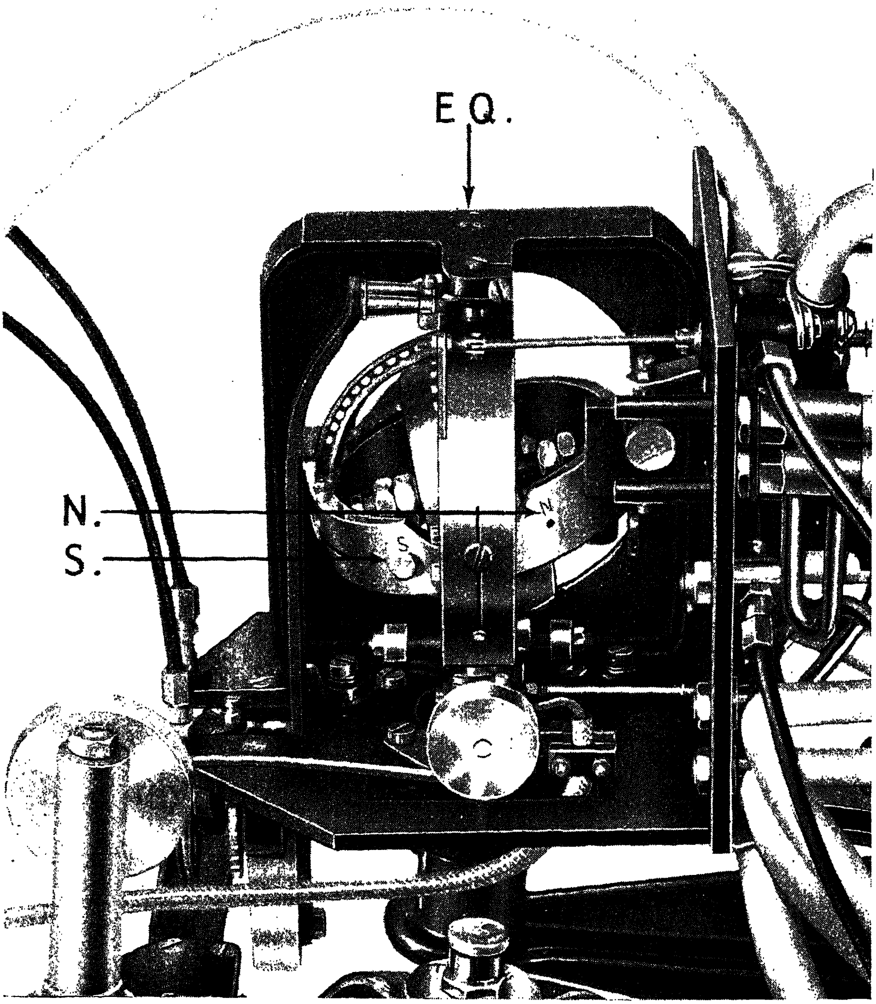


Fig. 53.—RUDDER CONTROL UNIT

Showing the latitude adjusting weight fixed in the position for southern latitudes.

Zones, and since such an error is between three and four times greater than that which is to be expected with the Smith automatic pilot when the gyroscope is correctly balanced, it has been considered advisable to

incorporate a device for rebalancing the gyroscope according to the latitude in which it is being used.

The adjustment is made by altering the position of a small weight, according to whether the aircraft is operating in Northern, Equatorial, or Southern latitudes. In Fig. 53 it will be seen that the weight is fixed to the inner gimbal ring at a point approximately 30 mm. to the rear of the starboard pivot of the inner gimbal ring. This is the "S" or Southern latitude position, and the "N" or Northern latitude position is similarly situated, but on the forward side of the same pivot.

When the aircraft is operating in the Tropics the small weight must be removed from the gimbal ring and fixed in the Equatorial position, which will be found on the top of the frame of the rudder-control unit.

Care must be taken when removing or fixing this small weight, and it must be securely fixed in whichever position it is required to be located. The weight is made in the form of a spring plug and should secure itself when pressed home. If the pin is found to be loose in its socket, the four sprung segments may be slightly opened with the blade of a penknife.

When the aircraft is operating in the North Temperate Zone or the South Temperate Zone, the small weight should be located on the inner gimbal ring in the positions marked "N" or "S" respectively.

DESCRIPTION OF THE ELEVATOR CONTROL AND ITS METHOD OF OPERATION

Although the same gyroscope is used to control the elevators and the rudder of the aircraft, the mechanism associated with the elevator control is distinct from that employed for the rudder control, and differs from it in certain important features. For example, in the case of the rudder control, the rudder valve is operated directly from the outer gimbal ring of the gyroscope, while in the case of the elevator control about to be described, the elevator valve is operated indirectly through the agency of a relay valve. A further important point of difference lies in the fact that whereas it is possible to adapt a gravitational device to provide an ultimate datum for the elevator control, no such device is available for the rudder control.

As has been stated earlier, the gyroscope of the rudder- and elevator-control unit is installed with its rotor axis in the fore-and-aft vertical plane. (The front end of the gyroscope axis is actually tilted slightly upwards, but this feature may be ignored for the moment.) It will, however, be evident from a consideration of Fig. 54, that if the aircraft suffers some disturbance which results in a change in its pitch attitude, then relative motion must occur between the inner gimbal ring and the main framework. The gyro itself and the inner gimbal ring will clearly maintain their original attitude in space, while the outer gimbal ring and all the rest of the apparatus must obviously tilt upwards or downwards according to the direction in which the aircraft itself has been disturbed.

The relative motion between the inner and outer gimbal rings which occurs with pitching movements of the aircraft is detected by means of a relay valve as shown in Figs. 54 and 55, and it is through the agency of this valve that the correcting movements of the aircraft elevators are made.

In the case of the rudder control, it was explained that azimuth deviations of the aircraft are detected by means of the rudder valve, the outlets of which are connected to the rudder servo-motor. It would equally be possible to detect the movement, between the inner and outer gimbal rings, which occurs with a pitch disturbance of the aircraft directly by means of the elevator valve.

Unfortunately, however, a valve of sufficient size to operate the servo-motors must inevitably possess a certain amount of friction and reaction due to air flow. While such reactions are not of great importance in the case of the rudder valve, it would be very serious if such forces were introduced to impede the free motion of the inner gimbal ring about its pivots. Briefly the reason for this is explained in the following paragraph.

A torque about the vertical axis of the outer gimbal ring, such, for example, as might be caused by friction or reaction of the rudder valve, will result in a precession of the gyroscope about the horizontal pivots of the inner gimbal rings, i.e. the azimuth torque will produce a pitch precession, and the pitch attitude of the aircraft will therefore be disturbed. But since the pitch datum of the gyroscope is eventually controlled by a gravitational device (to be described later) any such precession would quickly be corrected. Thus the pitch attitude of the aircraft is not affected by a small amount of reaction about the vertical axis of the outer gimbal ring.

In the case of the elevator control, however, any undue reaction about the horizontal pivots of the inner gimbal ring will cause an azimuth precession of the gyroscope, i.e. the aircraft will be deflected from its course, and it is therefore imperative that all possible friction should be eliminated from the horizontal axis if the directional accuracy of the gyroscope is to be preserved.

For this reason, a very small relay valve which possesses a negligible amount of reaction is employed to detect the relative motion between the inner and outer gimbal rings, and it is constructed in such a manner that the movements of its piston are amplified and relayed to a larger valve known as the main elevator valve, which controls the admission of the compressed air to the elevator servo-motor.

The Relay Valve

The relay valve thus performs the function of a mechanical amplifier, and, as may be seen by reference to Fig. 55, it contains two pistons, the inner or primary piston being connected to the inner gimbal ring of the gyroscope. The primary piston moves inside the main or secondary piston. The latter contains two exhaust channels.

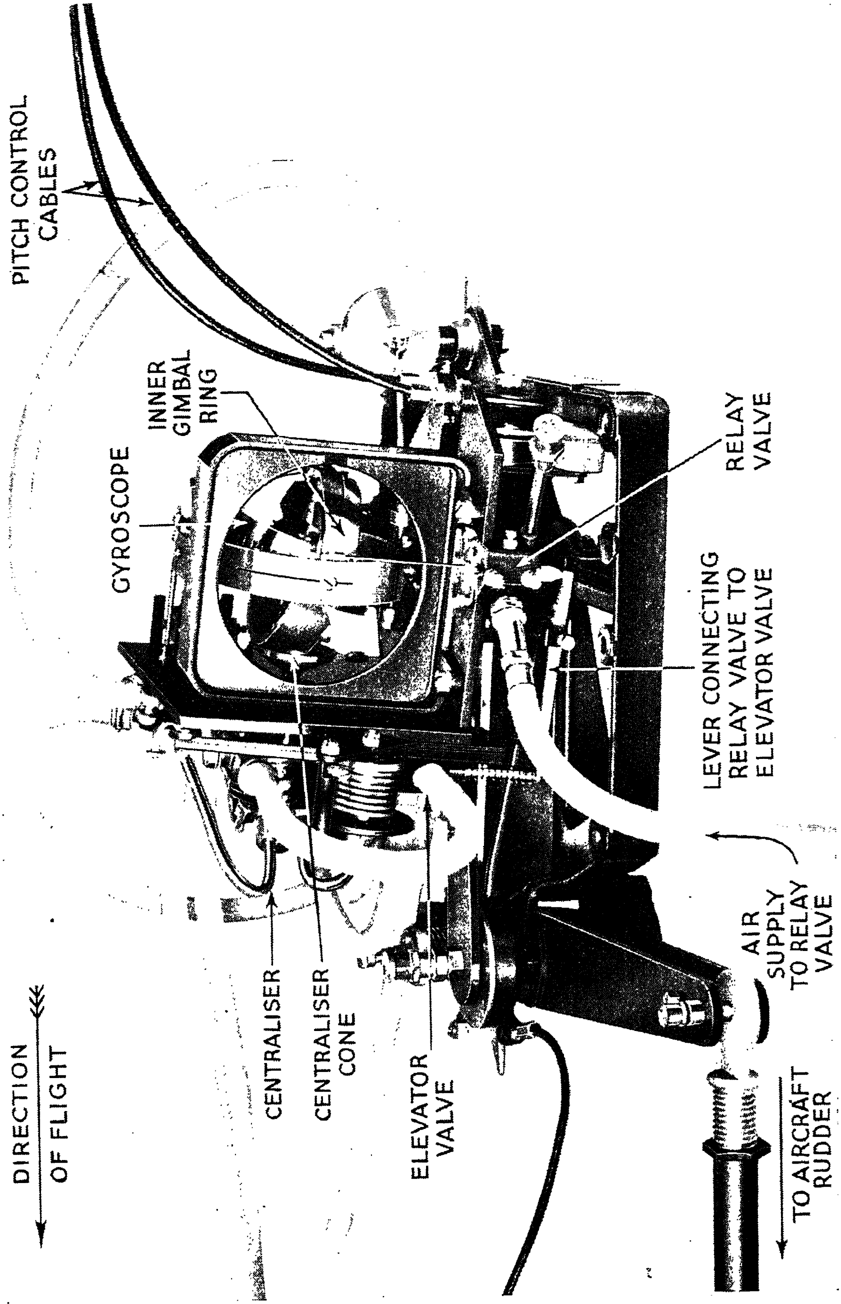


Fig. 54.—Rudder and elevator control from left-hand side, showing the connections between the inner gimbal ring, the relay valve, and the main elevator valve.

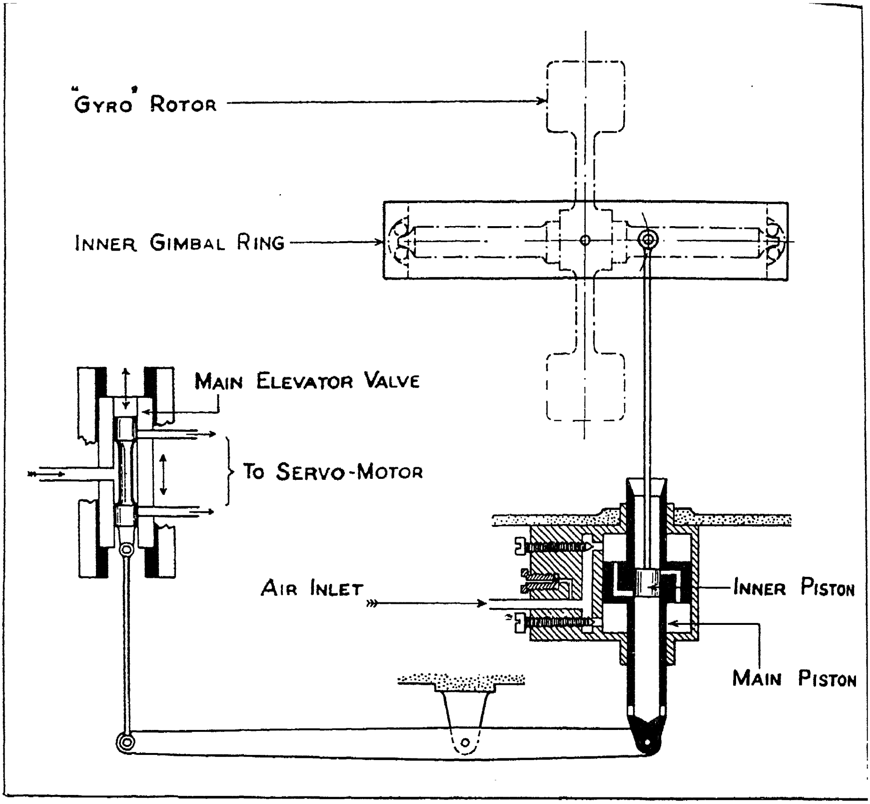


Fig. 55.—Showing the operation of the relay and main elevator valves

One connects with the top chamber of the valve with an exhaust port at the bottom end of the primary piston, and the other connects the bottom chamber of the valve with an exhaust port opposite the top of the primary piston.

Compressed air is supplied to the relay valve from the expansion chamber (Fig. 37, page 59), and enters the top and bottom chambers of the relay valve through the two adjustable needle throttles.

Details of a new relay valve, Type II, together with an illustration (Fig. 60), will be found on page 88.

Suppose that the primary piston is displaced slightly downwards, as will occur if the aircraft is pitched downwards. The primary piston will uncover the top exhaust port and the compressed air in the bottom chamber of the relay valve is thus allowed to escape. The excess pressure in the top chamber will then cause the main piston to travel downwards until both exhaust ports are again closed. The main piston thus moves

exactly the same distance as the primary piston, but since it derives the power for its motion from the compressed air in its two chambers, it possesses ample power to operate the piston of the main elevator valve without applying any load to the inner gimbal ring.

From the above description it will be evident that any motion of the inner gimbal ring about its pivots is exactly relayed to the main elevator valve, the piston of which behaves exactly as though it were connected directly to the inner gimbal ring except that it is incapable of applying any frictional loads.

Unlike the case of the rudder control, the servo-motor which controls the movements of the elevators is located on an entirely separate unit, which is illustrated in Fig. 56. It is, however, connected by suitable pipes to the two outlet ports of the main elevator valve, which may be seen in Fig. 57.

The " Follow-up " System

As in the case of the rudder control, it is necessary to incorporate a " follow-up " system between the piston of the elevator servo-motor and the main elevator valve in order to ensure that the amount of elevator angle applied for any given pitch disturbance is proportional to the magnitude of the disturbance. The " follow-up " system operates through the agency of a Bowden cable, and, as may be seen in Fig. 56, one end of the cable is connected with and operated by the elevator servo-motor. The other end of the Bowden cable is connected to a lever on the framework of the gyro unit by means of which the casing of the elevator valve may be caused to move upwards or downwards in its vertical guides. Any motion of the elevator servo-motor thus causes a proportional movement of the casing of the elevator valve.

The Elevator Control in Action

Let us suppose that some disturbance has occurred to the aircraft as the result of which its nose has been depressed. From Figs. 54 and 55 it will be realised that such a movement will constitute a slight anti-clockwise rotation of the aircraft, the gyro-framework, and hence the relay valve, about the pivots of the inner gimbal ring. That is, the body of the relay valve will rise relatively to its piston. This is equivalent to saying that the piston of the relay valve descends relatively to its casing, and the effect of such a motion is, as we have seen, to cause the main piston of the relay valve to descend also. The piston of the main elevator valve is thereby raised, and air is admitted to the elevator servo-motor which commences to raise the aircraft's elevators. As the servo-motor applies the elevator angle, however, the " follow-up " cable causes the casing of the elevator valve to rise so that it effectively " follows " the initial travel of its piston until the ports of the valve are once more closed. At this point, further travel of the elevator servo-motor, and

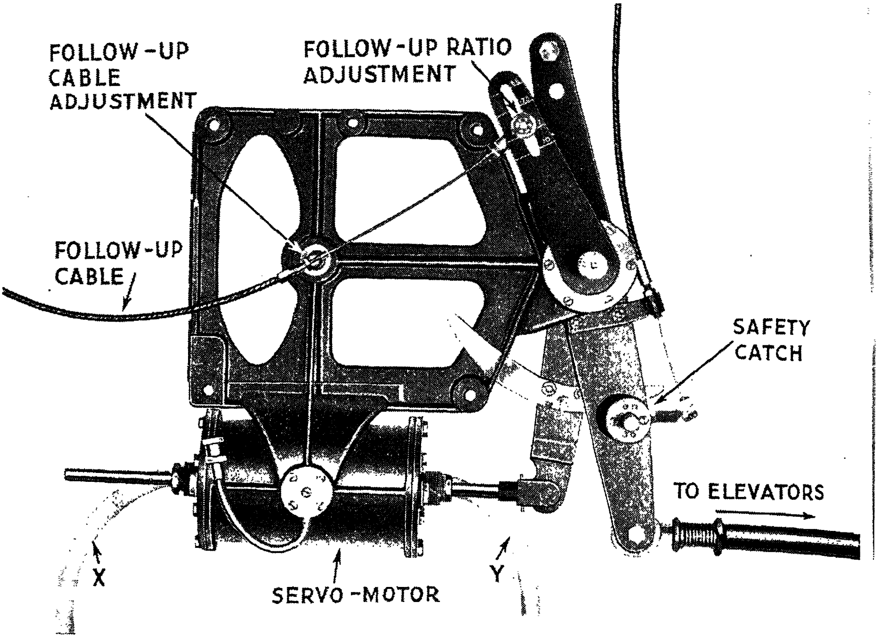


Fig. 56.—ELEVATOR SERVO-MOTOR AND MOUNTING

hence further application of elevator angle, is prevented. In this manner the degree of elevator angle applied is proportional to the actual pitch displacement of the aircraft, and, as in the case of the rudder control, as the aircraft returns to its correct attitude, the elevator angle is progressively reduced.

In order to render the pitch attitude defined by the gyroscope independent of any change in latitude or longitude or of the rotation of the earth, it is necessary so to control the gyroscope that it maintains a constant attitude with respect to the vertical. This control is exercised automatically by gravitational means.

It has hitherto been supposed that when the aircraft is in its level flight attitude, the pivots of the outer gimbal ring are exactly vertical. In actual fact this is not so, and the axis is slightly inclined to the vertical. Attached to an extension of the bottom of the outer gimbal ring is a weight W, Fig. 58, and while it will be realised that this weight would exert no influence if the outer gimbal axis was vertical, it will be clear that since the axis is not normally vertical, there will be a resultant gravitational torque about the outer gimbal axis on account of the weight.

Counteracting this gravitational torque, there is a second torque which is applied to the outer gimbal ring through the lever M, Fig. 58. The lower extremity of this lever is connected to one end of a coiled spring,

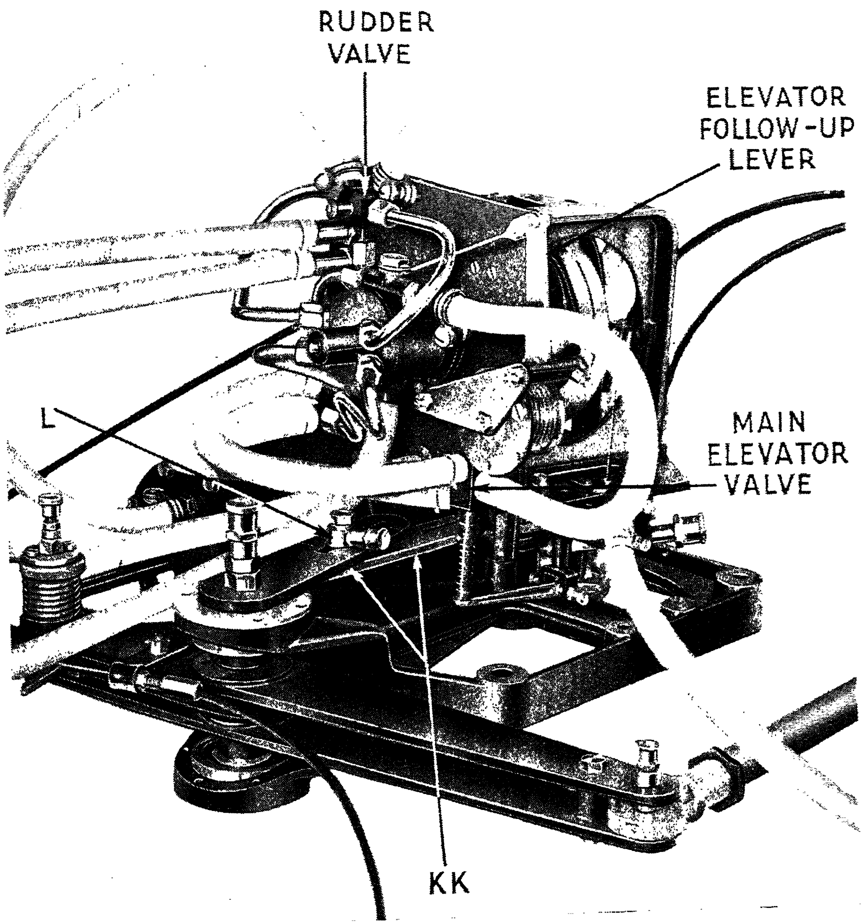


Fig. 57.—RUDDER AND ELEVATOR CONTROL UNIT
Showing the main elevator valve and rudder follow-up ratio arms.

the other end of which can be rotated by means of a Bowden cable from the pitch-control lever in the pilot's cockpit.

It will be recalled that the effect of a torque about the axis of the outer gimbal ring is to produce a precession of the gyroscope about the horizontal pivots of the inner gimbal ring, and since the pitch attitude of the aircraft is controlled by that of the gyroscope, it follows that any resultant torque about the outer gimbal axis must result in a change in the

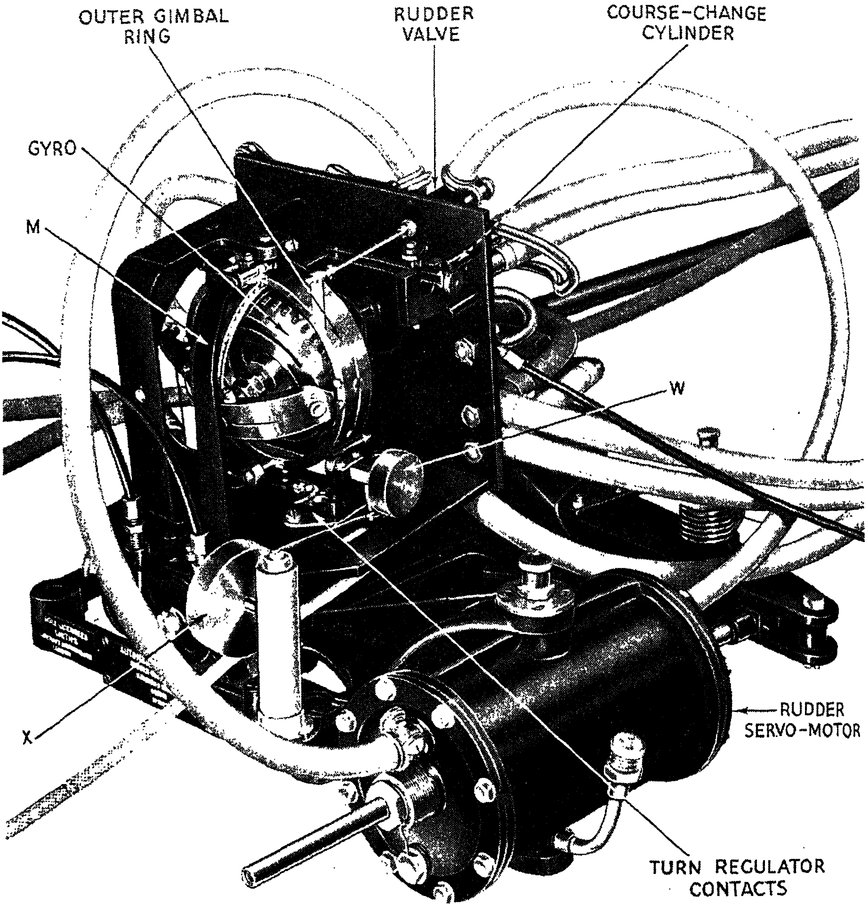


Fig. 58.—Rudder and elevator control unit
Showing the weights and Watt's linkage mechanism for setting the pitch datum.

pitch attitude. The gravitational torque due to the weight W and the spring torque due to the lever M oppose each other, and since the gyroscope must continue to precess so long as the two torques are unequal, it follows that the stable attitude of the aircraft is that attitude at which the gravitational torque exactly opposes the spring torque.

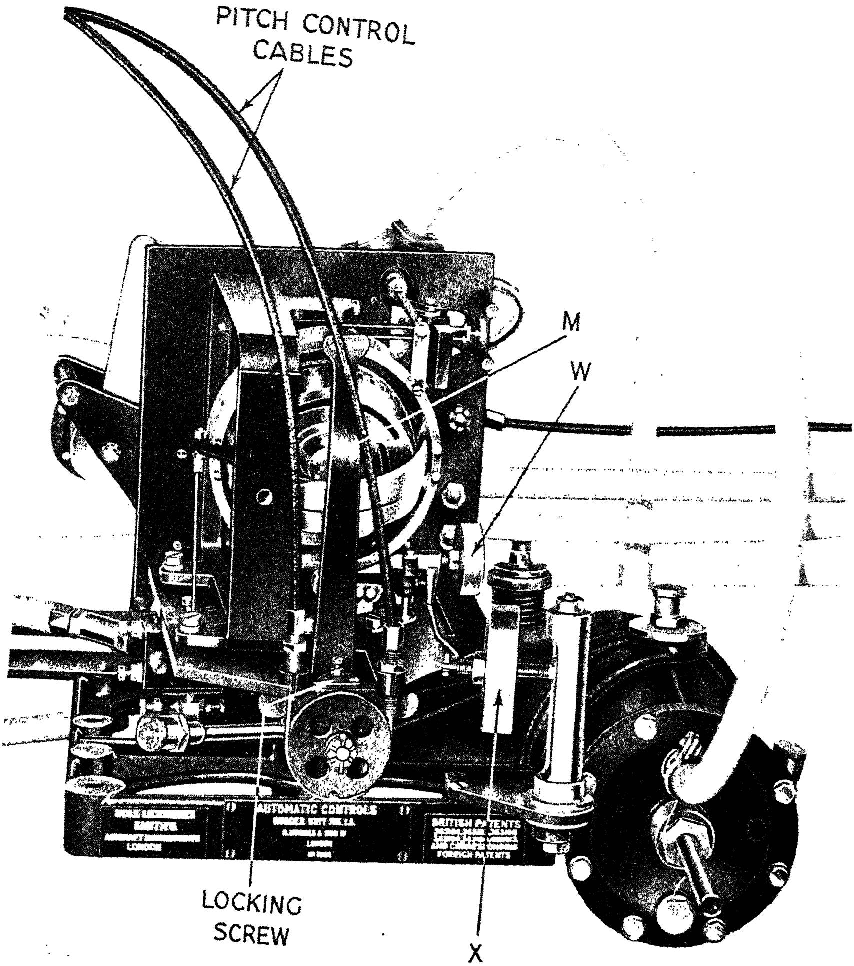


Fig. 59.—Rudder and elevator control unit from the rear
Showing the pitch control mechanism.

When the pilot wishes to change the pitch attitude of the aircraft, he makes an alteration to the spring torque by means of the Bowden cables from the pitch-control lever in his cockpit, and the gyroscope will then precess to a new attitude at which the gravitational torque again balances the spring torque.

It has been implied above that the gravitational torque is due solely

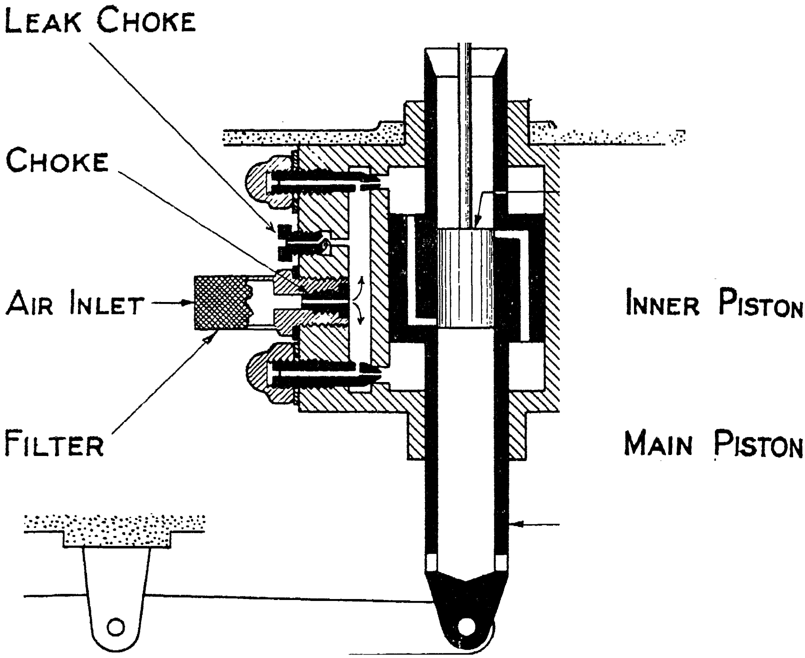


Fig. 60.—RELAY VALVE, TYPE II

to the addition of the weight W to the extension arm on the outer gimbal ring, and while the addition of this weight alone would permit the gear to function as described, it would be sensitive to centrifugal force which would cause small inaccuracies in the pitch control when the axis of the gyroscope is displaced laterally from the fore-and-aft plane of the aircraft, as will occur during a turn.

In order to make the unbalanced mass consisting of the outer gimbal ring and the weight W insensitive to lateral accelerations, the weight is divided into two parts, one of which is attached to the outer gimbal ring as explained, and the other of which is shown at X, Fig. 59. This second weight is carried by a pivoted arm which is connected to the outer gimbal ring by a link, the whole arrangement forming a "Watt's linkage."

This arrangement operates in exactly the same manner as the single weight described above, so far as pitch angle changes are concerned, but it has the advantage of complete insensitivity to lateral accelerations.

RELAY VALVE, TYPE II

A new design of relay valve to take the place of the relay valve described on page 80 (Fig. 55) has been produced to reduce the risk of obstruction of the small adjustable chokes in the previous design.

As will be seen in Fig. 60, the principal changes consist of the substitution of fine jets in place of the needle type previously described, and the addition of a mains choke in the air supply filter (now known as Type IIA), the gauze of the latter being of much finer mesh than originally.

The relay valve of the aileron unit has been similarly modified.

This modification has been made as it was found that the very small annular gap between the top of the needle chokes previously employed, and their seatings, was liable to become blocked. The new type of jet is screwed down until the conical point is making a light contact with the seating, and air is supplied through a hole of ·007-in. diameter drilled down the centre of the jet. It will be realised that a relay valve of this type is prone to high-frequency hunting. This can be stopped by opening the leak choke (Fig. 60) and thereby lowering the operational pressure.

These relays are adjusted by the makers and should not require subsequent attention. If, however, one of the jets should become choked so that the main valve is no longer accurately positioned, the jets may be removed, after taking off the dome nuts and washers, and carefully cleaned. Care must be taken during replacement to screw them down lightly on to their seatings, to avoid distortion of the main cylinder of the relay.

Should it be necessary at any time to move the leak choke, it should be carefully adjusted until a hunt of the relay, started by deflecting it with a finger-nail and suddenly releasing, subsides in a few seconds. The leak choke should be at least a half-turn open and the main valve should be firmly located after these adjustments have been made.

DESCRIPTION OF THE AILERON CONTROL AND ITS METHOD OF OPERATION

In the case of the rudder and elevator control mechanism described in the preceding pages, it has been seen that the basic principle of the gear is the employment of a gyroscope to provide a stabilised datum from which deviations of the aircraft can be detected. A single gyroscope provides the datum for both the rudder and elevator controls, but in the case of the aileron control, a separate gyroscope is used.

The basic principle of the aileron control is the provision by the gyroscope and its associated mechanism of an imaginary vertical datum plane. This imaginary vertical datum is defined with a high degree of

accuracy, and when the aircraft rolls as the result of some atmospheric disturbance, a sensitive valve detects the departure of the aircraft from its normal level attitude and causes the ailerons to operate to correct the disturbance. The aircraft is thus maintained accurately on an "even keel."

The Control Unit

It is appropriate to remark at this stage that the aileron control unit of the Smith automatic pilot is designed to keep the aircraft laterally level under all conditions, even when executing a turn. In general, it is quite unnecessary to make fast turns when flying under automatic control, and the absence of any banking is thus scarcely noticeable. Although it is comparatively easy to design a gyroscopic aileron control which would permit the aircraft gradually to take up its normal bank angle during a turn, yet it may be pointed out that at the conclusion of a turn with such a system, the aircraft will no longer be flying on an even keel, and several minutes may elapse before the wings are accurately level again. While such a condition is not of serious consequence if the aircraft is only performing normal flying duties, in the case of photographic survey work or high precision bombing the utmost accuracy and stability of attitude are essential. For such purposes, the precision of the Smith automatic pilot is particularly satisfactory.

The actual mechanism of the aileron control falls naturally into two main divisions, the first consisting of the gyroscope and the associated mechanism whose sole function is to define the vertical plane. The second part consists of the valves and other mechanism whose function is to detect any departure of the aircraft from its normal level attitude and to apply the necessary correcting movements to the ailerons.

The definition of the vertical datum is achieved by the gyroscope with the aid of the associated mechanism shown in Figs. 61 and 62. In Fig. 61 the gyroscope and gimbal rings have been dismantled from the complete unit in order to show the erecting mechanism, which may be seen on the right-hand side, but in looking at this figure it must be noted that the photograph has been taken from an unusual angle—from almost underneath—and the normal position may best be seen in Fig. 62.

The gyroscope, like that of the rudder and elevator unit, spins at a speed of about 11,000 r.p.m. The gimbal rings are very similar in construction and support the gyroscope so that its axis lies athwartships. The weight W, which is rigidly attached to the outer gimbal ring, hangs vertically beneath the gimbal system as shown in Figs. 62 and 63.

The inner gimbal ring is pivoted about the vertical axis and is connected by a link to the piston of a small valve A, as shown in Figs. 61 and

63. This valve is carried on a plate integrally with the outer gimbal ring, and its function is to detect any relative movement between the inner and outer gimbal rings, such as would occur if the aircraft yaws. This valve, which is known as the precessing valve, is supplied with compressed air and when any relative movement takes place between the inner and outer gimbal rings, it admits the compressed air through one of its exit ports to one or other side of the "precessing cylinder" B.

The precessing cylinder consists of a small double-acting piston and cylinder, the piston being attached by means of a link to a part of the outer supporting framework. The admission of compressed air to either side of the precessing cylinder thus results in the application of a torque to the outer gimbal ring which is itself carried on pivots which lie in the fore-and-aft line of the aircraft.

Associated with the precessing valve A and situated immediately behind it, is an important spring mechanism known as the erector mechanism, which may be seen at C, Figs. 61 and 63. When the inner and outer gimbal rings of the gyroscope are exactly at right angles to each other, the spring mechanism is neutral and exerts no force in either direction, but when the inner gimbal ring is displaced in one direction or the other from its normal position, not only is the precessing valve A brought into action, but the spring mechanism C applies a torque which tends to return the inner gimbal ring to its normal position. By means of these three components, the precessing valve A, the precessing cylinder B, and the erector mechanism C, the outer gimbal ring is maintained in the vertical plane in the following manner.

The Aileron Control in Action

Let us suppose that the aircraft is flying on a straight and steady course, and that, for some reason, the weight W, together with the outer gimbal ring, has become displaced from the vertical. It will be clear that a gravitational torque will result about the pivots of the outer gimbal ring, the axis of which lies parallel to the fore-and-aft axis of the aircraft. This gravitational torque will produce a precession of the inner gimbal ring about its vertical axis. Precession of the inner gimbal ring through a very small angle from its normal position at right angles to the outer gimbal ring brings the precessing valve A into action, and this valve, in turn, operates the precessing cylinder B which causes a torque to be applied to the outer gimbal ring in such a sense as to oppose the gravitational torque due to the displacement of the weight W and the outer gimbal ring from the vertical. The azimuth precession of the inner gimbal ring is therefore limited to that small angle which suffices to operate valve A.

In addition to the operation of valve A, however, the precession of the inner gimbal ring from the orthogonal position immediately results in the

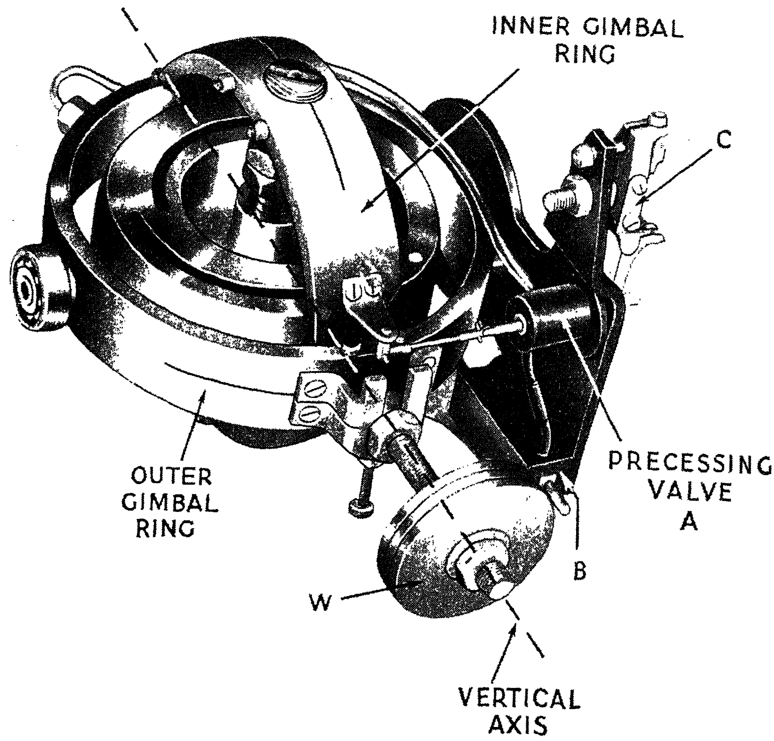


Fig. 61.—Aileron gyroscope in gimbal rings

It should be noted that in this view the gyroscope is shown on one side in order to show the precessing valve and erecting mechanism on the right.

application of a small restoring torque by the spring C. This torque acts about the vertical axis of the inner gimbal ring, and hence causes a precession of the gyroscope and outer gimbal ring about the longitudinal axis in such a sense as to return the outer ring and the weight W towards the vertical.

The return of the weight W and the outer gimbal ring to the vertical plane is a very gradual process, and is not necessarily a perfectly continuous one. It is important to note that it is not directly due to the gravitational torque applied by the displaced weight, but is caused by the departure of the inner and outer gimbal rings from the mutually orthogonal position.

It will thus be seen that in straight and steady flight, at any rate, the gyro system shown in Fig. 61 always tends to erect towards the

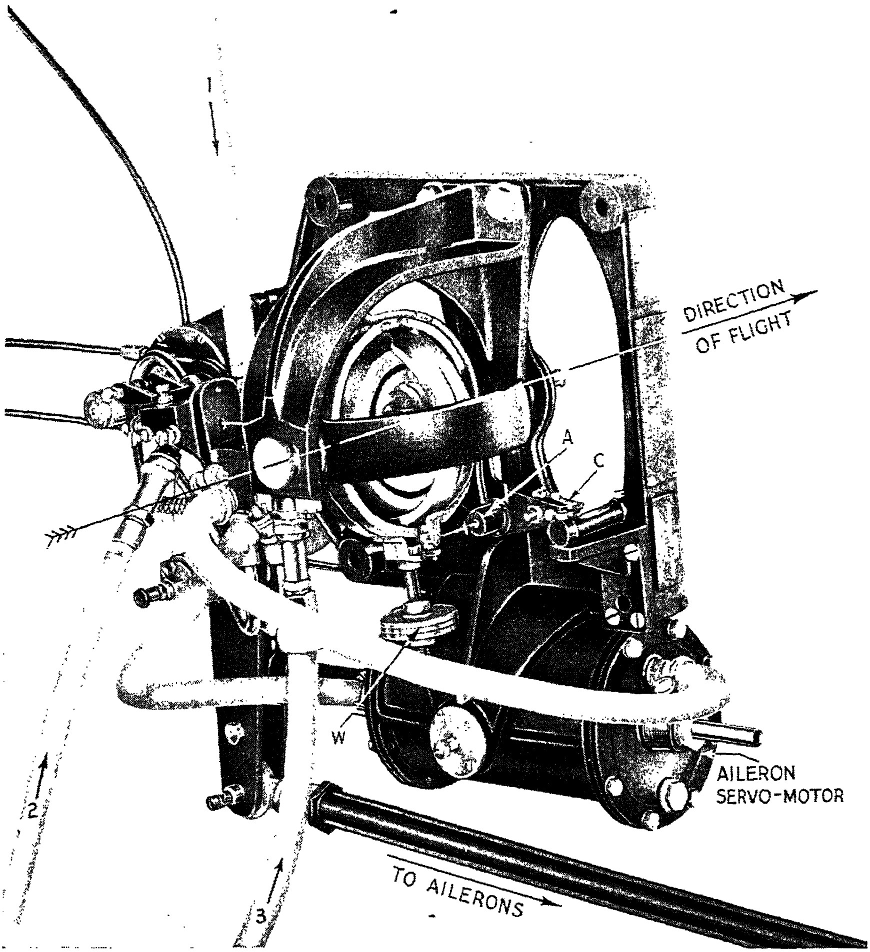


Fig. 62.—AILERON CONTROL UNIT FROM THE RIGHT-HAND SIDE

Pipe (1) supplies the compressed air from the main control cock to the centraliser; pipe (2) supplies the relay valve from the air-expansion chamber, and pipe (3) is the supply to the gyro spinning jets.

vertical. It remains to consider the behaviour of the system when influenced by the accelerations which arise during a turn.

A Steady Turn

Let it be supposed that the aircraft is making a steady turn. It will be clear that in addition to the normal gravitational force on the

weight W, there is now a centrifugal force which exerts a torque about the longitudinal axis of the outer gimbal ring. This torque, which is proportional to the air speed of the aircraft and also to the rate of turn, causes the gyroscope and inner gimbal ring to precess in azimuth.

Provided that the mass and radius of action of the weight W are correctly chosen in relation to the angular momentum of the gyroscope rotor and to the forward speed of the aircraft, it will be clear that the rate of precession of the inner gimbal ring in azimuth may be made equal to the rate of turn of the aircraft. Assuming, therefore, that the forward speed of the aircraft is maintained at the predetermined figure, no relative movement will occur between the gyroscope and the aircraft, and the outer gimbal ring will not be displaced from the vertical plane by the action of the centrifugal force during a turn. Furthermore, if the outer ring is displaced initially from the vertical plane, it will subside to the vertical during a turn in the same manner as already described for straight flight.

The effect of making a turn at an air speed other than that for which the mechanism has been adjusted is to cause a gradual erection of the weight W to a false datum, and the aircraft will therefore no longer be controlled into an accurately level attitude. The amount of bank acquired, however, will be small, since it is determined by the difference between the actual speed of the aircraft and that for which the unit has been adjusted, and this adjustment is always made by the makers for the normal cruising speed of the aircraft. Except when extreme precision is required, turns may be made at other air speeds, but in this case a slight banking is to be expected.

In case it should become desirable to adjust the weight W so that accurately level turns can be made at some other air speed than that for which it has been set, the procedure is to fly the aircraft at the speed required and note whether the aircraft tends to bank inwards or outwards during a turn. If the aircraft tends to bank into the turn, as it will do if it is being flown at a higher speed than that for which the unit has been tuned, the moment of the weight is excessive and should be reduced, either by raising the weight or, in extreme cases, by replacing it by a smaller one. If the aircraft tends to bank out of the turn, the moment of the weight must be increased, either by lowering it, or by the addition of a further weight. The adjustment is independent of altitude, provided that a constant indicated air speed is maintained, because the true air speed and the rotor speed will vary in unison when the air density is changed.

We have now shown how the comparatively simple mechanism shown in Fig. 61 defines the vertical, and although the manner of its operation is somewhat complicated, it forms in practice a gyro-vertical of the highest precision and reliability. It remains, however, to describe briefly the manner in which the gyro-vertical is employed to control the ailerons.

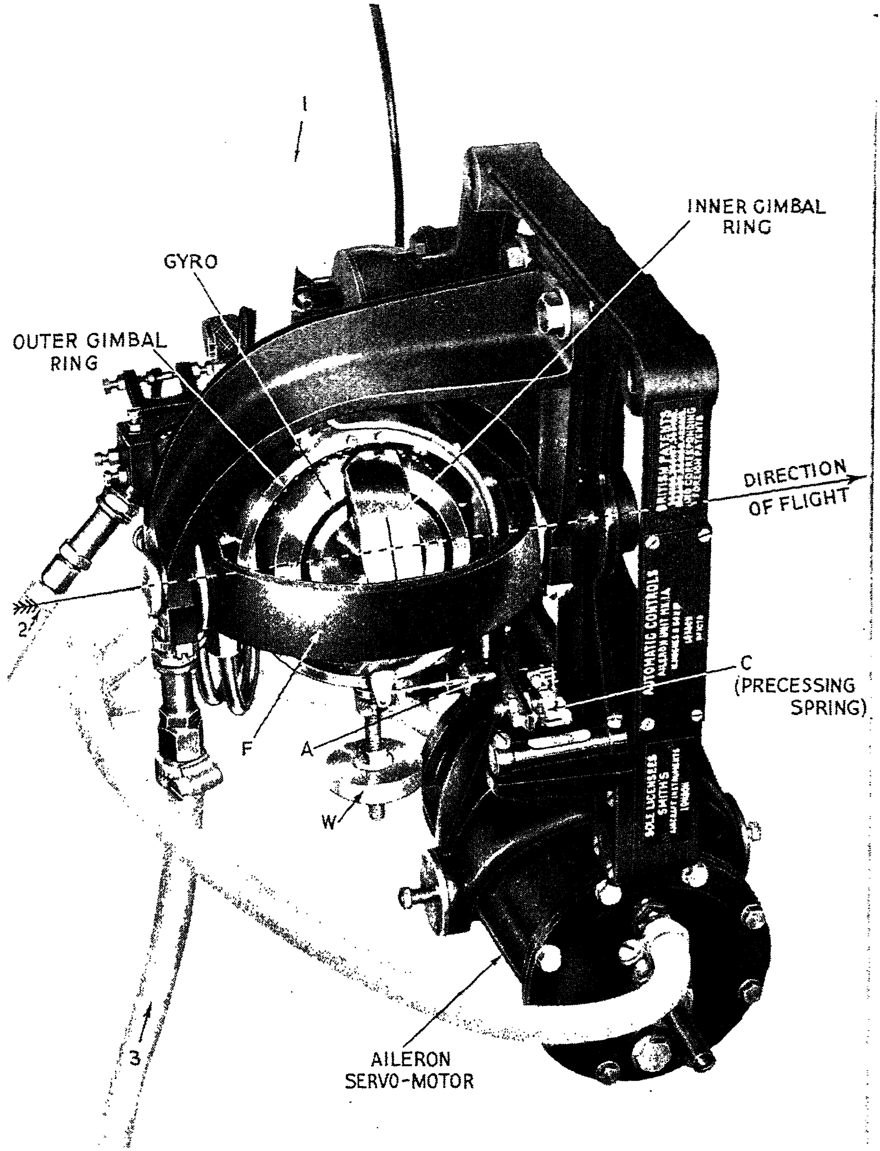


Fig. 63.—Aileron control unit from the right-hand side
Showing the erecting mechanism.

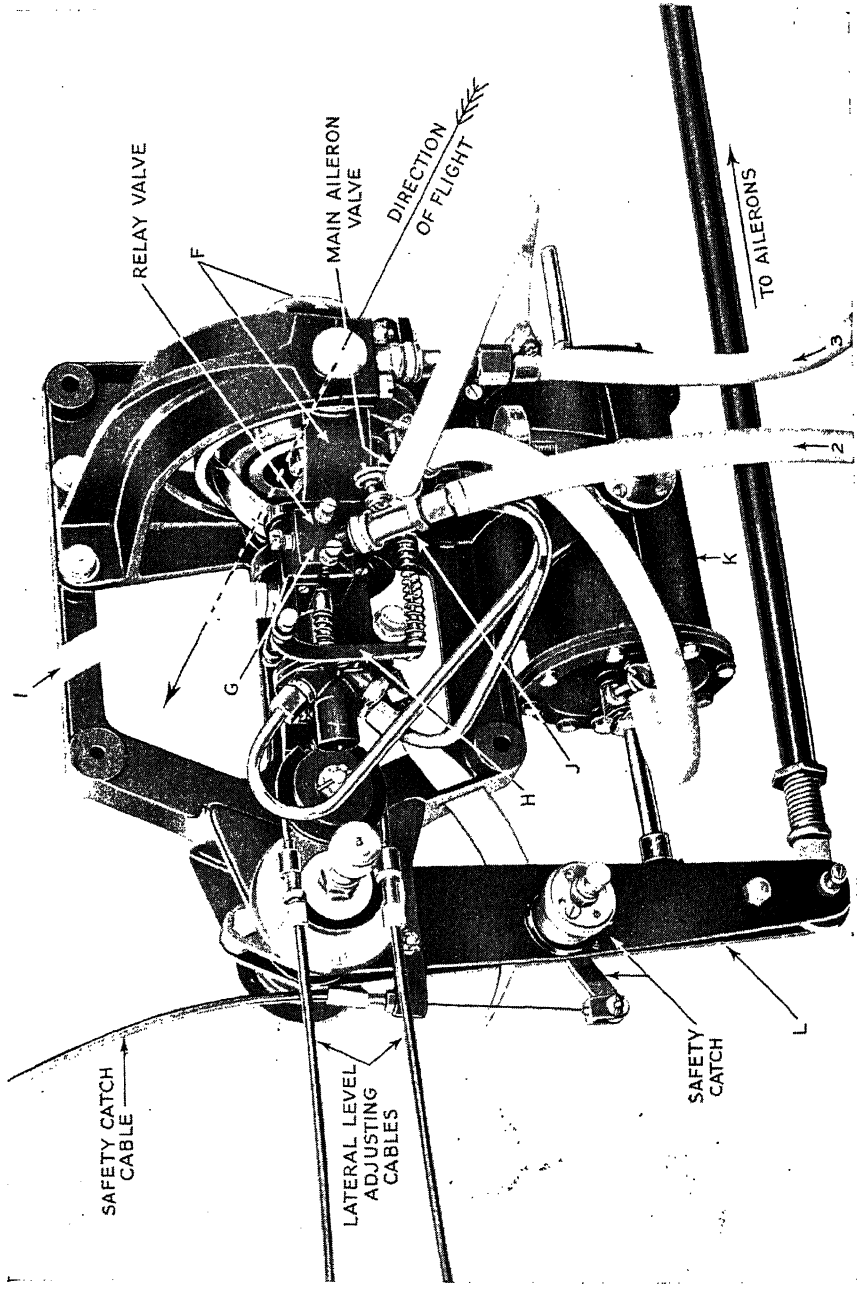


FIG. 64. AILERON CONTROL UNIT, REAR LEFT-HAND VIEW

The Aileron-control Unit

Referring to Figs. 63 and 64, which show the complete aileron-control unit from two sides, it will be seen that the gimbal ring assembly is supported in a ring-shaped framework F, which is itself supported in the main framework by bearings on the same axis. The aileron-control unit is installed in the aircraft so that the axis of support of the gimbal system and of the frame F lies parallel with the fore-and-aft axis of the aircraft. When the aircraft rolls, therefore, the outer gimbal ring remains vertical, while relative movement takes place between the outer gimbal ring and the supporting framework. This relative movement is used to operate a small relay valve G of almost identical construction to that employed on the elevator-control unit described elsewhere. The secondary piston of the relay valve is connected by the lever H (Fig. 65) with the piston of the main aileron valve J which controls the admission of compressed air to the aileron servo-motor K. The servo-motor piston is connected to the aileron bar L, the lower end of which is attached to the aileron-control system of the aircraft.

As in the case of the rudder and elevator controls, it is necessary to incorporate a follow-up system in order to limit the application of aileron angle to an amount proportional to that through which the aircraft has rolled. The exact arrangement of the follow-up system is not easy to see in the photograph, Fig. 65, but it may here be remarked that the motion of the servo-motor piston is connected through the aileron bar L and the levers PP to the frame F on which the relay valve and the main aileron valve are mounted.

When a roll displacement of the aircraft occurs, the operation of the relay valve and the aileron valve causes the servo-motor to apply the appropriate correcting movements to the ailerons. As the servo-motor operates, however, the levers PP cause the frame F to rotate in its bearings in such a sense as to "follow" the apparent displacement of the inner piston of the relay valve. In this way the application of aileron angle is limited to an angle proportional to the actual roll displacement of the aircraft in very much the same manner as was decribed for the elevator control.

In order to adjust the actual magnitude of the correcting movements applied to the ailerons for any given roll displacement of the aircraft, provision is made for adjusting the relative lengths of the two levers PP by means of an adjustable pin which may be seen in Fig. 65. As in the case of the rudder and elevator controls, this adjustment is made on installation and should not subsequently be changed.

INSTALLATION AND ADJUSTMENTS

Installation

It must be emphasised that the work of designing the layout of the various components of the automatic pilot in a new type of aircraft

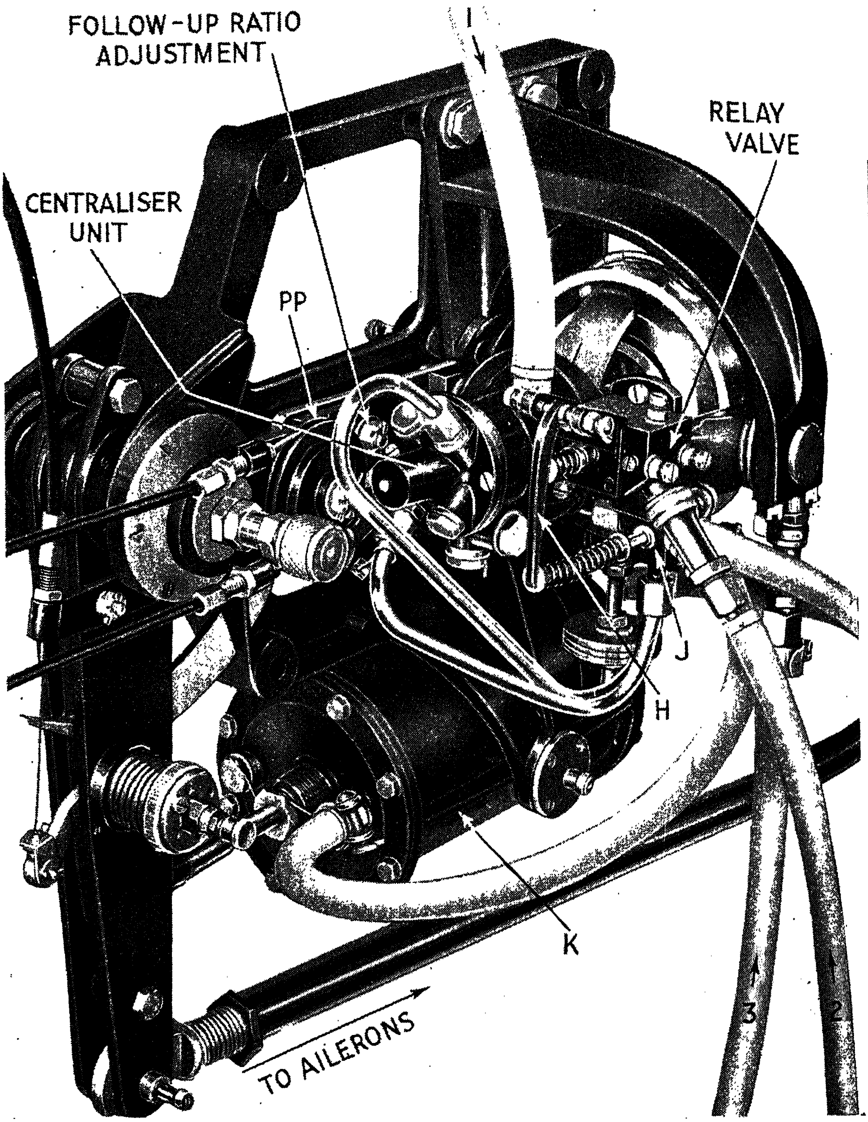


Fig. 65.—AILERON-CONTROL UNIT
Showing follow-up adjustment.

must be undertaken only by an engineer who is fully qualified and trained in such work. These notes are not intended as a guide to installation and must not be employed as such.

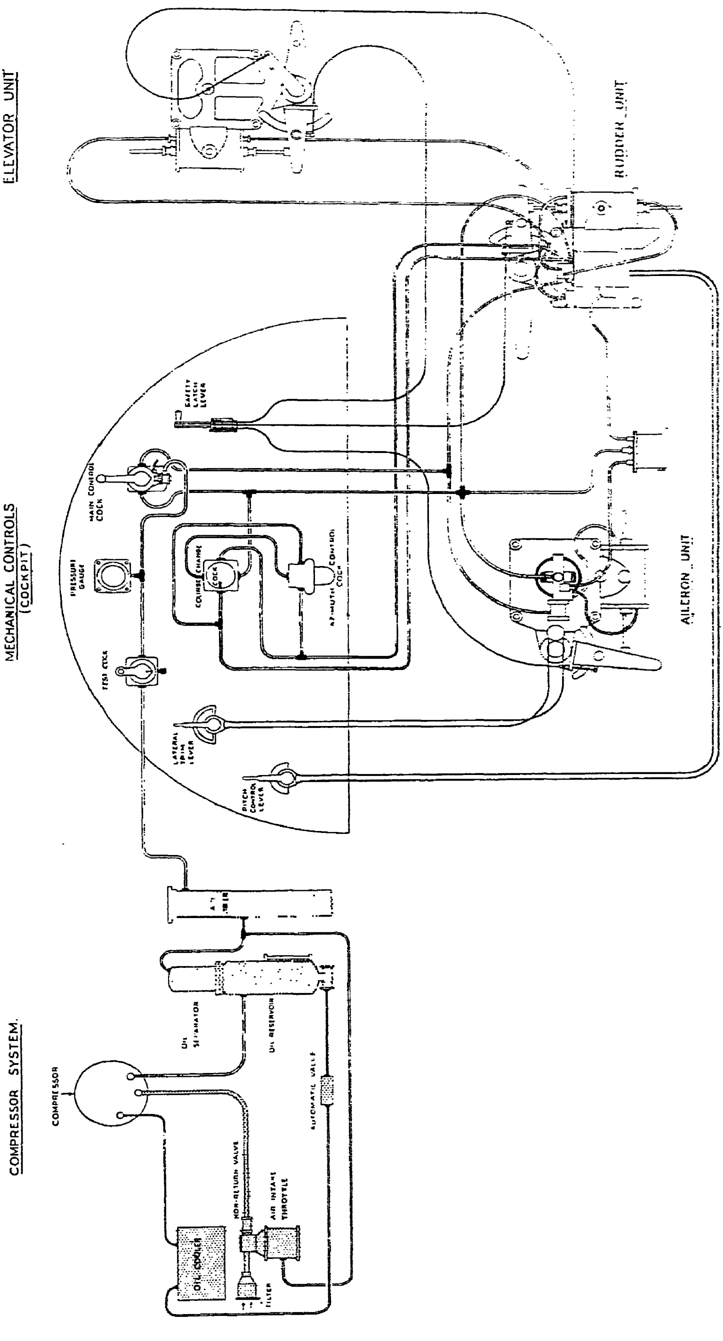


Fig. 66.—DIAGRAMMATIC LAYOUT OF AILERON CONTROLS (MK. 1a INSTALLATION)

It must also be understood that the task of removing the units of the automatic pilot or reinstalling them should be undertaken only by personnel with experience of this work.

The initial installation will normally be made by the manufacturers, and the following tests and adjustments will be made during and after installation. They are not required to be repeated unless the installation has been removed from the aircraft.

General

(1) Ensure that all pipe lines are firmly secured and clean internally.

(2) See that all pipe connections are tight and securely locked.

(3) Test all pipe joints and connections for leaks. This should be done by supplying compressed air to the test cock, which should be turned to the "TEST" position. If a solution of soapy water or thin oil is applied to each joint, any leaks can be easily detected.

(4) Make sure that all Bowden cable runs are as straight as possible and cleated at frequent intervals. Sharp bends must be avoided.

(5) See that all nipples on the ends of Bowden cables are securely soldered and cleaned of flux.

(6) See that all control cocks and control levers are securely bolted in position.

(7) See that the rubber pipes on the control units do not foul any moving part, and are of sufficient length to prevent kinking or pulling.

(8) *Safety catches.*—The lengths of the Bowden cables which connect the safety-catches lever (Fig. 36, page 59) with the three safety catches on the rudder unit, the elevator unit, and the aileron unit respectively, must be so adjusted that the catches engage perfectly and without shake when the lever is at the "IN" position. Care must be taken, however, to ensure that the catches disengage completely when the lever is at the "OUT" position, and there should be at least four notches to spare in order that stretching of the cables may not result in incomplete withdrawal of the catches.

(9) The connecting rods or cables which connect the various servo-motors of the automatic pilot to the aircraft controls must be adjusted in relation to the travel of the aircraft control surfaces. Each of the control surfaces in turn should be placed exactly midway between its extreme positions, and the connecting rods or cables should then be adjusted so that the servo-motor pistons are in the middle of their respective cylinders.

With the safety catches "IN" the controls must each be tested separately, as follows:

Hold the control column in its extreme forward position (i.e. elevators down). Then withdraw the safety catches and note that a further forward movement of the control column is possible. Re-engage the

safety catches, and repeat the procedure with the control column right back.

This test must be carried out for all three controls, elevators, rudder, and ailerons, and it ensures that at no time can an undue strain be placed on the aircraft's controls by the servo-motors if any of the servo-motor pistons should travel to the limits of their strokes.

Rudder and Elevator Control

(1) Special care must be taken to ensure that this unit is level, both fore-and-aft and laterally, when the aircraft is in its flying attitude.

(2) Care must be taken when fitting the pitch-control cable to the rudder unit. The pitch-control lever (Fig. 34) must be at the "0" position before removing the small locking screw which locks the pitch-control pulley to the rudder unit (see Fig. 59).

(3) Care must be taken to ensure that the elevator-control unit is installed so that the axis of the servo-motor is within 5° of the horizontal when the aircraft is in its flying attitude, in order to prevent the possibility of lubricating oil draining from the cylinder of the servo-motor into the rubber supply pipes.

(4) *Elevator follow-up cable.*—With the safety catches engaged and the elevators set in line with the tail plane, the length of the Bowden cable connecting the elevator servo-motor (see Fig. 56) with the lever which moves the casing of the elevator valve (Figs. 50 and 57) must be adjusted until the casing of the valve is approximately centrally placed in relation to its piston. This adjustment should preferably be made with a supply of compressed air connected to the test cock, and with the main control cock at the "SPIN GYRO" position, in order to give proper location to the elevator relay valve.

If the aircraft is fitted with an adjustable tail plane, as in older types of aircraft, care should be taken to see that the tail is set at the zero or level-flight position when aligning the elevators and tail plane before adjusting the Bowden cable.

Aileron Control

(1) Special care must be taken to ensure that the aileron unit is mounted truly athwartships when the aircraft is in flying attitude. A bubble-level is provided on the unit so that it may be set accurately level.

(2) *Ratio arms.*—The follow-up ratio must be set to the required ratio by adjusting the pin (Fig. 65) if the correct ratio is known. If the aircraft is the first of its type to be fitted with the automatic pilot, this adjustment may have to be made during the flight tests.

Automatic Cut-out

The automatic cut-out should be so adjusted that when the elevators are moved just beyond the desired limit of travel in either direction, one

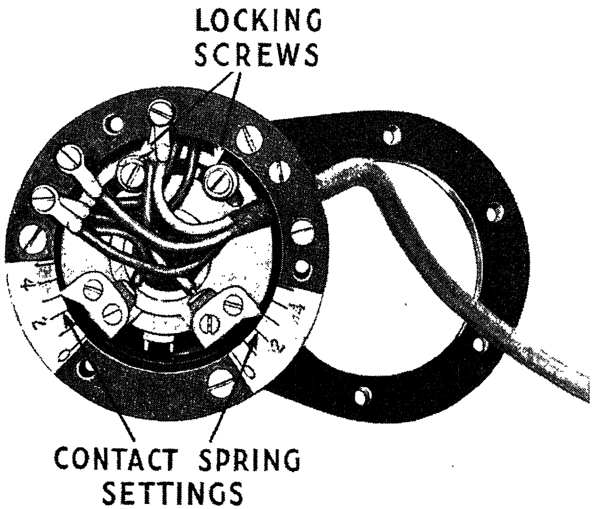


Fig. 67.—Automatic cut-out, top view of interior

of the fixed contacts should leave the segment of the cut-out (see page 60). The setting of the cut-out will be individual to a given type of aircraft, since it depends on the gearing ratio between the servo-motor and the elevators.

The following procedure should be followed for ascertaining the correct settings for the cut-out contacts when this is necessary:

(1) Remove the cover of the cut-out.

(2) Engage the safety catches.

(3) Connect the electrical circuit to a 12- or 24-volt supply, as the case may be.

(4) Turn the main switch (if fitted) to "ON."

(5) Set the cut-out switch to "IN."

(6) Set the tail plane, if adjustable, to the zero or level-flight position. Then set the elevators by means of the control column to the central position in line with the tail plane and press the resetting switch. At no time during the rest of the adjustments should the resetting switch be pressed.

(7) With the aid of an inclinometer, move the elevators 5° upwards.

(8) By visual examination, determine the appropriate contact spring in the cut-out which, for this upward movement of the elevators, must separate from the contact segment.

(9) Disconnect the plug of the quick-release unit from its socket, and at the same time note which pin holes of the socket correspond with the red and yellow spots engraved on the plug.

(10) Connect a voltmeter or test lamp to the holes in the socket which correspond with the red and yellow spots marked on the plug. This action puts the voltmeter or test lamp in series with the cut-out contacts.

(11) Slacken the locking screws (Fig. 67).

(*Note.*—Before applying a screwdriver to loosen or tighten the locking

screws, it is always advisable temporarily to disconnect the plug of the cut-out to prevent an accidental short-circuit.)

(12) Move the appropriate contact spring until the voltmeter or test lamp indicates that the contact is *just* broken. The setting of the contact spring as shown by the pointer and the scale on the cut-out should be noted for other installations.

(13) Tighten the locking screw.

(14) Now set the elevators 5° downwards from the central position, and repeat the operation for the other contact spring.

(15) Replace the cut-out cover and reconnect the plug of the quick-release unit.

GROUND TESTING, AIR TESTING, AND FAULT TRACING

I. Ground Testing

Compressed-air Supply

The final adjustments after installation of the automatic pilot require a supply of compressed air. This may be obtained from a portable compressor plant, a compressed-air bottle with a suitable reducing valve, or any other convenient source. The free quantity of air required is about 4 cu. ft. per minute, at a pressure of about 35 lbs./sq. in., and it is very important that the air supply should be both clean and free from excessive moisture.

The compressed-air supply should be connected to the union provided on the test cock (see page 49), and the cock should be turned to "TEST."

General

(1) The aircraft must be set up in the attitude of level flight and the wings must be laterally level.

(2) The gyroscopes may now be run up to speed by turning the main control cock to "SPIN GYRO." The cock must be allowed to remain in this position for at least five minutes before proceeding further.

(3) Check that the air pressure as indicated by the pressure gauge in the pilot's cockpit is approximately 35 lbs./sq. in.

(4) Then, with the rudder bar and the control column in the positions for straight and level flight, the main control cock may be turned smartly to the "IN" position. The air pressure may drop slightly, but if the change is more than 2–3 lbs./sq. in., a leaking pipe or joint should be suspected. If a reducing valve is used in the compressed-air supply pipe, it will probably require readjustment when the main control cock is turned to "IN" on account of the increased consumption of air.

Important.—During ground testing, care must be taken to ensure that the servo-motors are never allowed to reach the ends of their travel.

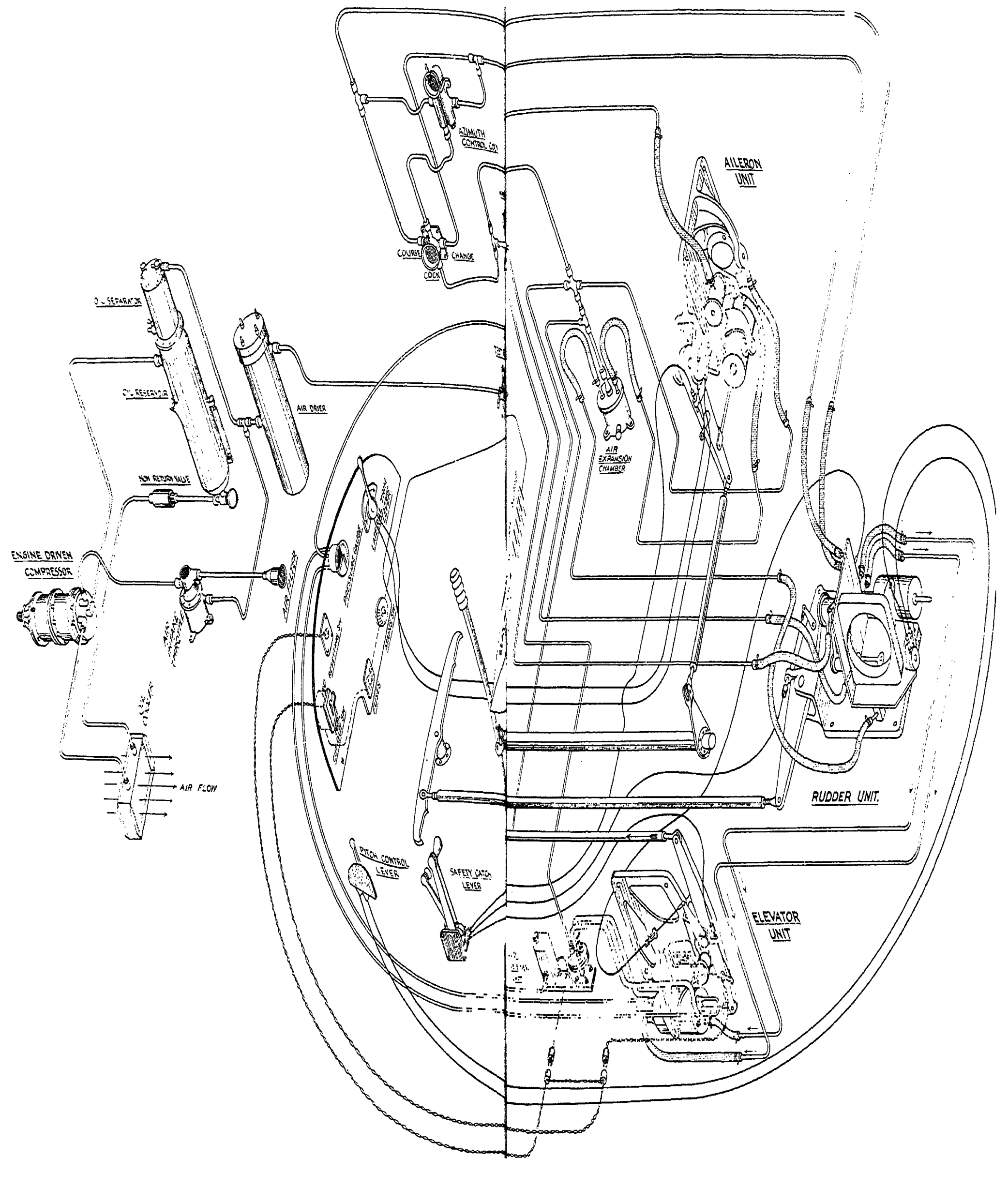


Fig. 68.—Complete Install matic Pilot

This precaution is necessary on the ground because the aircraft is not responding to the movements of the control surfaces.

Rudder and Elevator-control Unit

(5) If a sudden "kick" of the control column in a backwards or forwards direction is observed on turning the main control cock to "IN," a further adjustment is required to the follow-up cable (see page 101, paragraph 4) as the piston of the elevator valve is evidently not central in its casing. The Bowden follow-up cable should therefore be adjusted (see Fig. 50) after turning the main control cock back to "SPIN GYRO."

If the direction of the "kick" was forward, the Bowden adjuster must be screwed slightly outwards, and *vice versa*.

This procedure must be repeated until no "kick" of the control column is noticed on turning the main control cock to "IN." It is quite probable, however, that a further slight adjustment to the follow-up cable will be required during the flight test in order to eradicate any "kick" as the automatic pilot is brought into action. This is because there is generally a difference between the exact position of the elevators required in level flight and the position which would seem to be that position when on the ground.

(6) With the main control cock at "IN," operate the pitch-control lever and observe the subsequent movement of the elevators, to check that they move in the correct direction. The elevators should of course move downwards when the pitch-control lever is moved forwards, but if the reverse effect is observed, the cables to the control lever are incorrectly connected and must be reversed.

(7) Great care must be taken to make sure that the supply pipes to the elevator servo-motor are correctly connected. (Pipe X in Fig. 50 *must* be connected to X in Fig. 56, and Pipe Y *must* be connected to Y, and NOT *vice versa*.)

(8) Check the direction of operation of the course-change cock by turning it to port and starboard, and observing that the aircraft rudder *commences* to move in the correct direction. If the rudder moves in the wrong direction, the pipes are wrongly connected and must be reversed.

In a similar manner check the azimuth control cock by first turning the course-change cock to "OBSERVER" and then operating the azimuth cock.

N.B.—In carrying out this test it is *very important* not to leave either the course-change or the azimuth control cock in the port or starboard positions for more than a few seconds, and immediately it is seen that the rudder is moving in the correct direction, the cock must be returned to "STRAIGHT." If this is not done, the gyroscope might reach the limit of its travel (since the aircraft is not responding to the directions of its rudder while on the ground), and serious damage might be done to the gyroscope.

Aileron Control

(9) Check the Bowden system between the lateral-trim lever and the aileron-control unit ; the lever, the pulley, and the eccentric on the pulley shaft should be simultaneously in their mid-positions. Check that the cables are not crossed by moving the lateral-trim lever with the main control cock in the " IN " position. The left aileron should rise when the lever is moved towards the left, and *vice versa*.

(10) The functioning of the aileron-control unit should be checked in the following manner. Turn the main control cock to " SPIN GYRO," and then apply about 5° of aileron in either direction by means of the control column or aileron wheel. Then turn the main control cock to "IN," and note that the control column or wheel returns to its zero position within approximately one minute. Repeat the test with the opposite aileron displacement.

(11) Check that the aileron cables are correctly connected by noting that the aileron droops on that side towards which the weight W (Fig. 62) is displaced.

Compressor Ground Test

If an engine-driven type of compressor is fitted it may be tested by running the engine to which it is fitted while on the ground.

Make sure that the oil reservoir is filled to the correct level.

II. Flight Tests

The various adjustments described above can be made very closely on the ground, but the final settings can be made only during flight ; when an installation is completed or modified in any way, it is, therefore, always necessary to carry out a preliminary flight for the purpose of checking the various adjustments.

The flight tests should be carried out in fair-weather conditions at a height of not less than 3,000 ft., and the following procedure should be adhered to :

(1) Before taking off, make sure that the pilot has engaged the safety catches. It may be impossible to engage them during flight.

(2) Make sure that all the control cocks and levers are in their correct positions.

(3) After taking off, release the compressor brake, if fitted. Then check that the air pressure is approximately 35 lbs./sq. in., and turn the main control cock to " SPIN GYRO."

Note.—Make sure that the pilot realises that the safety catches must *never* be withdrawn when the main control cock is at the " IN " position except to regain manual control in the event of a serious emergency.

(4) Allow the gyroscopes at least 5 minutes to reach their correct speed, and meanwhile ensure that the pilot has trimmed the aircraft to

fly "hands off" on a level course at the assigned air speed. (See footnote on page 112.)

(5) Turn the main control cock smartly to the "IN" position, and the automatic pilot should take over control smoothly. See that the air pressure does not drop appreciably.

(6) If a sudden "kick" on the aircraft's control column is noticed on turning the main control cock to "IN," a further adjustment of the elevator follow-up cable is required, as follows:

(*a*) Turn the main control cock back to "SPIN GYRO."

(*b*) If the direction of the "kick" was forward, the Bowden adjuster must be screwed slightly outwards, and *vice versa*. (See Fig. 48.)

(*c*) Return the main control cock to "IN" and repeat the adjustment if necessary until there is no "kick."

(7) With the main control cock at "IN," test the pitch-control lever and check that the aircraft responds in the right direction. The lever should operate in the same sense as the control column. It should operate smoothly, and there should be little if any lost motion, but it must not be forgotten that the aircraft will take 15 to 20 seconds to take up its new attitude.

(8) Test the operation of the course-change cock in all positions. Check the rates of turn in each direction by means of a stop-watch.

(9) Make sure that the aircraft remains laterally level when turning, i.e. see that the turns are "flat turns."

If the aircraft banks either into or out of the turn, the weight W (Fig. 62) on the aileron-control unit must be adjusted. If the aircraft banks into the turn, the weight must be raised or even replaced by a smaller one, while if the aircraft tends to bank out of the turn, it must be lowered or replaced by a heavier one. (See page 94.)

(10) Return the main control cock to "SPIN GYRO," and fly the aircraft manually in a straight line, but with one wing about 5° down. While in this attitude, turn the main control cock smartly to "IN" and note that the aircraft returns to its correct lateral level in approximately 1 minute.

Any slight and constant error in lateral trim should be corrected by means of the lateral trim lever. This lever should operate smoothly and have little or no lost motion.

Follow-up Ratios

The correct setting of the follow-up ratios will normally be made by the manufacturer's engineers at the time of installation, and when these adjustments have been determined for a particular type of aircraft, all other installations in the same type can be set to the same ratios. Once the correct gearings have been determined, they will need no further adjustment and they should not be altered. The correct settings are generally indicated on a small plate fitted in a prominent position in the aircraft.

Important Note.—All adjustments to the automatic pilot, other than those made by means of the control cocks or levers, must be made with the main control cock at the "SPIN GYRO" position. To attempt to do otherwise is an unnecessary and dangerous procedure.

III. Procedure for Tracing Faults

Failure of the automatic pilot is not likely to occur during normal use if the regular inspections laid down in the recommended maintenance schedule are carried out with proper care. Should trouble be experienced at any time, however, the pilot's evidence together with the following notes will be of assistance in tracing the cause of failure.

A. *Incorrect Air Pressure*

The air-pressure gauge provides an invaluable guide for tracing the nature of any fault, and pilots should always be trained to check the air pressure at frequent intervals when the automatic pilot is in use.

(1) *Air pressure below normal in all three positions of the main control cock.*

The following points should be examined for possible causes:

(*a*) Insufficient oil in the reservoir.

(*b*) Leakage in the pipes of the compressor system.

(*c*) Choked oil filters, either on the compressor or at the bottom of the oil reservoir.

(*d*) A faulty compressor.

(*e*) Air-intake throttle.

If the oil level in the reservoir is found to be exceptionally low for no apparent reason, the various pipes should be carefully examined for signs of leakage, and if the cause of the loss of oil is not revealed by this examination, the oil reservoir and pipes connected with it should be tested with compressed air.

If no signs of leakage can be found, and the filters are perfectly clean, then the compressor should be examined and tested.

(2) *Air pressure below normal when the main control cock is at the* "SPIN GYRO" *and* "IN" *positions, but normal at the* "OUT" *position.*

A leakage in the pipes should be suspected, and this is likely to be in either:

(*a*) The pipes leading to the spinning jets;

(*b*) The pipes connected to the expansion chamber and relay valves; or

(*c*) The pipes connected to the course-change cock.

An inspection of the various pipes should be made, and if no fracture is evident, a compressed-air test should be made. Any serious leakage can be detected by the sound of the escaping air. Greater silence for this test will be obtained if paper wedges are inserted to prevent the gyroscopes rotating, but care must be taken not to confuse the noise of the

air emerging from the spinning jets with that escaping from a leaking pipe or connection.

3. *Air pressure below normal only at the* "IN" *position.*

The following points should be specially examined :

(*a*) The pipes leading from the main control cock to the centralisers.

(*b*) The leather cup-washers in the centralisers.

(*c*) The pipes from the centralisers to the valves.

(*d*) The pipes from the valves to the servo-motors.

(*e*) The centralisers and servo-motors.

The most probable cause of a fault in this category is a defective leather cup-washer on one of the centraliser pistons. The washer may be soaked for 12 hours or more in neat's-foot oil, or in extreme cases they may have to be replaced by the spare set to be found in the tool kit.

The action of the centralisers should be carefully watched while an assistant operates the main control cock. If they do not withdraw sharply and firmly when the main control cock is turned to "IN," there will be a serious leakage of air and loss of compression in the servo-motors.

B. *Failure of the Apparatus while the Pressure Gauge is showing Normal Pressure.*

The following points should be examined for possible causes :

(*a*) An obstruction in one of the fine passages in the valve systems.

(*b*) Choked filters in the pipes supplying air to the spinning jets, to the air expansion chamber, or to the relay valves.

(*c*) A sticking relay valve, gummed-up with oil or blocked by ice formation.

(*d*) Loss of speed by the rotor of the rudder gyroscope. This can easily be detected by the excessively large rate of turn which results.

(*e*) Loss of speed by the rotor of the aileron gyroscope which leads to incorrect lateral trim during a turn.

In tracing the cause of a failure in this group, if no mechanical fault is evident, the air filters in the expansion chamber and control units should be examined and cleaned.

A temporary failure might possibly be caused in very cold weather by a seizure of one of the relay valves due to ice formation. Evidence of such a failure will not be found during a subsequent examination, but the possibility should be borne in mind.

If the nature of the failure is not disclosed by this examination, a full ground test should be made as described above. Should such a test indicate that the cause of the fault lies in one of the valves or the pipes leading to it, the pipe may be removed for examination and cleaning, but the valves themselves should not be interfered with. They may be cleaned with a mixture consisting of two parts of pure petrol and one part of oil, and then re-oiled without removing them from the control units. (Petrol containing tetra-ethyl lead must NOT be used.)

If it is suspected that either of the gyroscopes is running below its normal speed, the acceleration of the rotors should be observed when the compressed air is turned on. No remedy, other than the cleaning of the appropriate air filters and the lubrication of the rotor bearings, should be attempted.

Important.—Whatever the nature of the fault may be, it is very important that no attempt should be made to interfere with the gyroscopes, the gimbal rings, the various balancing weights, or the valves. Any change of adjustment of these parts will affect the tuning of the apparatus, and this can be rectified only by the makers.

C. *Automatic Cut-out and Quick-release Units. Procedure for Tracing Faults.*

(*a*) Disconnect the quick-release unit's plug from its socket.

(*b*) Connect a 12- or 24-volt battery to the circuit, as the case may be, and turn on the main switch if one is fitted.

(*c*) Place the cut-out switch to " IN."

(*d*) Engage the safety catches and move the aircraft's control column through its full backwards-forwards range to make sure that they are engaged.

(*e*) Press the resetting switch. An audible " click " should be heard from the automatic cut-out, signifying the operation of the coil inside. If no click is heard, inspect the fuse, and if this is satisfactory, the cut-out should be replaced. If a new one is installed, see that the contact springs inside are correctly set.

(*f*) Connect a 12- (or 24-) volt test lamp to the holes in the socket of the quick-release unit which correspond with the red and yellow pins of the plug (see page 102, paragraphs 8, 9). With the elevators in their central position, again press the resetting switch and note that the lamp remains alight without flickering while the elevators are moved through a range of 5° upwards and downwards from the central position. The lamp should become extinguished if the elevators are moved beyond this range, but if it fails to glow or flickers within the range of $\pm$ 5° from the central position, dirty contacts on the segment in the cut-out should be suspected and the unit should be removed for overhaul.

(*g*) Remove the cover of the quick-release unit (Fig. 43), and test for mechanical freedom of the air valve and linkage by depressing the relay armature.

(*h*) Place the cut-out switch in the " OUT " position and re-connect the quick-release unit in the circuit.

(*i*) Press and release the resetting switch. The relay of the quick-release unit should operate and hold itself in the operated position. If the relay does not operate on pressing the resetting switch and the wiring is found to be in order, the unit must be removed for repair. If the relay operates, but fails to hold itself in the operated position, it is probable

that the spring contacts on the side of the relay are dirty. If it operates before the resetting switch is pressed, and fails to release when the elevators are moved to their extreme up or down position, a short-circuit may be suspected, probably at the wiring tags at the bottom of the relay-contact springs.

INSTRUCTIONS TO PILOTS

Before Taking Off

(1) *Engage the safety catches*

This is done by releasing the safety-catch lever and then moving *each* of the aircraft-control surfaces through its *full* range in turn by means of the control column and rudder bar, in order to ensure the proper engagement of the catches.

(2) See that the main control cock is at " OUT."

(3) See that the test cock is at " FLYING."

(4) See that the course-change cock is at " STRAIGHT."

(5) Set the pitch-control lever central.

In the Air

When the automatic pilot is required in use :

(1) Release the air-compressor brake.

(A compressor brake is fitted only in the case of the windmill-driven type of compressor.)

(2) Turn the main control cock to " SPIN GYRO " and check the compressed-air pressure.

(3) Trim the aircraft as accurately as possible for straight and level flight at the assigned air speed.[1]

(4) Set the cut-out switch to " IN."

(5) Press and release the resetting switch.

(6) Turn the main control cock smartly to " IN." The automatic pilot should take over the control of the aircraft without any disturbance.

(7) Recheck the compressed-air pressure.

(8) Adjust the fore-and-aft level of the aircraft as required by means of the pitch-control lever.

The aircraft will take about 15 seconds to reach its steady attitude after adjusting the pitch-control lever, and after making each such adjustment the resetting switch must be again pressed to recentre the contact segment of the automatic cut-out.

It should be noted that changes in pitch attitude while under automatic control can only be made by means of the pitch-control lever.

[1] The automatic pilot is adjusted to take over control without a " kick " on the control column at one particular air speed. This air speed should be known to the pilot, and if it is desired to alter the assigned air speed, the maintenance mechanic must be requested to make the necessary adjustment.

Any attempt to alter the attitude by adjusting the tail-plane setting or elevator trimming tabs will merely result in a continuous and unnecessary load on the elevator servo-motor and the associated parts of the aircraft without effecting any change in attitude.

The tail-plane setting should always be adjusted so that an average zero indication is given on the differential pressure gauge.

(9) *Level flight*

The automatic pilot controls the *attitude* but not the *altitude* of the aircraft. To fly at a constant height, the pilot should observe the engine r.p.m. required to maintain level flight at a given air speed while the aircraft is under manual control.

Then, having put the automatic pilot into operation, the pitch-control lever may be adjusted to give the correct air speed at the observed engine speed. The aircraft should then maintain a constant altitude.

It should be remembered that when the pitch-control lever is operated, the aircraft will not reach its new controlled attitude and speed for about 15 *seconds.*

(10) *Changes of course*

For large changes of course—

(*a*) With the Mark 1A course-change cock: Turn the cock to "PORT" or "STARBOARD" as required, and return it to "STRAIGHT" on completion of the required turn.

(*b*) With the Type II course-change cock: Turn the lower cock to "HAND." (This operation cuts out the aileron control.) Then turn the upper cock to "PORT" or "STARBOARD" as required. The pilot can now control the ailerons by means of the control column, to keep the lateral bubble central during the turn. On completion of the turn, put the upper cock to "STRAIGHT," restore the lateral level of the aircraft, and only then return the lower cock to "AUTO."

Small changes, of course, are most easily effected by means of the azimuth control cock. If a Type II course-change cock is fitted, the azimuth control cock may be operated at any time when the course-change cock is at "STRAIGHT." If a Mark 1A course-change cock is fitted, it must be turned to the position marked "OBSERVER" before the azimuth-control cock will operate.

(11) *Return to manual control*

Turn the main control cock to "SPIN GYRO." The pilot can then control the aircraft manually. When the main control cock is at "SPIN GYRO," the gyroscopes are maintained at their correct speed and the automatic pilot can again be brought into immediate use by turning the main control cock back to "IN," as described above.

(12) *Automatic cut-out*

The object of the automatic cut-out is to protect the structure of the aircraft at high speed from the effects of any sudden and excessive movement of the elevators while under automatic control. It is set to operate and cut out the automatic pilot in the event of the elevators moving more than a predetermined amount up or down from their normal position.

The pilot's controls for the automatic cut-out are :

(1) Cut-out switch.

(2) Resetting switch.

Cut-out switch.—When the cut-out switch is at the " OUT " position, the cut-out is short-circuited and thus put out of action. It should always be turned to " IN " when the aircraft is flown at or above its assigned speed when under automatic control.

Resetting switch.—Since the normal position of the elevators must obviously vary with different settings of the pitch-control lever and with changes of aircraft loading, a " resetting switch " is provided, and this should be pressed and released whenever the pitch attitude or the loading of the aircraft is changed.

Before Landing

(1) Turn the main control cock to " OUT."

(2) Withdraw the safety catches.

The safety catches provide a complete mechanical disconnection between the automatic pilot and the aircraft controls.

They must *never* be withdrawn when the main control cock is at " IN," except in the case of an extreme emergency, as damage to the gyroscopes may result.

They should never be withdrawn in flight except prior to landing, as it is almost impossible to re-engage them while in flight, should it be required to do so.

(3) Apply the compressor brake, if fitted.

The compressor brake may be applied during flight if desired, but it must be applied *only* when the main control cock is at " OUT," as a considerable loss of oil from the compressor system may otherwise result.

Notes on the Use of the Automatic Pilot for Photographic Survey Work or Bombing Purposes

The automatic pilot is capable of maintaining the aircraft far more steadily on its course than the most skilled human pilot. Its use therefore results in a much higher standard of accuracy than can possibly be obtained by manual control.

To obtain the highest accuracy, it is clearly essential that the aircraft should maintain a constant height at the speed for which the aileron gyroscope has been adjusted. It is advisable that the pilot

should make a note of the engine speed required at the assigned air speed to maintain level flight under manual control at the height at which it is required to fly. Under automatic control, the attitude of the aircraft will be maintained constant by the automatic pilot, and in order to maintain a constant height, it is necessary to adjust the engine r.p.m. to the required value.

When the automatic pilot is employed during bombing operations, the necessary data for setting the bomb sight should be obtained while flying under automatic control. Then the aircraft should be manœuvred under manual control into a suitable position for the attack, the automatic pilot re-engaged and the course-change cock turned to "OBSERVER." This operation places the directional control of the aircraft in the hands of the bomb aimer, who will then be able to control the line of attack by means of the azimuth control cock. For the highest accuracy it is desirable that the automatic pilot should be engaged at least 1 minute before the bomb release in order that the aileron gyroscope may have time to settle to the true vertical and thus ensure that the aircraft is accurately level.

In multi-engined aircraft, care should always be taken to synchronise the engines accurately in order to ensure that the fore-and-aft axis of the aircraft coincides with the line of flight.

If the height should change appreciably as the result, for example, of convection currents, slight and judicious adjustments to both the pitch-control lever and the engine throttle will quickly restore the altitude without seriously affecting the forward speed. On regaining the desired altitude, these controls should be restored to their original positions.

MAINTENANCE SCHEDULE

While individual circumstances and operating conditions may demand some modification of the inspection procedure recommended in the following pages, it is pointed out that this schedule has been compiled as the result of long experience, and it is strongly recommended that it should be followed as closely as circumstances permit.

Lubricating Oil

The same oil which is employed in the air-compressor system should be employed for the lubrication of the various valves, servo-motors, and gyroscopes. The oil used must comply with the British Air Ministry Specification No. D.T.D.44b.

No oil must be used unless it complies with this specification.

The following oils, which are distributed throughout the world, comply with the above specification :

Intava Utility Oil.
Intava Servo Fluid.
Shell Anti-freezing Oil.

Inspection between Flights

(1) Receive pilot's report after landing.
(2) Ensure that the safety-catch lever is at "OUT."
(3) See that the main control cock is at "OUT."
See that the course-change cock is at "STRAIGHT."
See that the pitch-control lever is central.
See that the test cock is at "FLYING."
(4) Check the level of the oil in the oil reservoir.

Daily Inspection

Air Compressor

(1) Inspect compressor for cracks or damage.
(2) See that all pipe connections are tight.
(3) Inspect windmill for damage if an air-driven compressor is used.
(4) See that the windmill works freely when the compressor brake is "off."
(5) Drain water trap (if fitted).

Oil Reservoir

(1) Fill the oil reservoir up to the 1-pint mark, but *not* above. *Use only the specified oil.*
(2) After filling, turn off taps so that the oil gauge is isolated for flight.
(3) See that the pipe unions are tight.
(4) Drain the separator (if a Mark III oil reservoir is used) and shut the drain cock after draining.

Rudder-control Unit

(1) Gently displace the lever which couples the relay valve to the main elevator valve, to make sure that both valves are free.
(2) Make sure that the casing of the elevator valve moves freely in its slides under the action of its associated lever and return spring.
(3) Examine the safety catch for shake or wear.

Aileron-control Unit

(1) Gently displace the lever which couples the relay valve and the main aileron valve, to make sure that both valves are free.
(2) Examine the safety catch for shake or wear.

Elevator Unit

(1) Examine the safety catch for shake or wear.
(2) Examine both ends of the follow-up cable for signs of fraying. Replace if any broken strands are found.

Controls

(1) See that the safety piston on the main control cock works freely.

(2) Examine the safety-catch lever for security and correct functioning. Make sure that there are four notches of travel to spare after all catches are disengaged.

(3) See that the course-change and azimuth cocks work freely.

(4) See that the pitch-control lever is free.

(5) Examine the pressure gauge for visible defects and for security of connections.

(6) Examine all control units for security of fastenings.

5 Hours' Inspection

Chemical Air Drier (if fitted)

Remove and clean the interior container and recharge with silica gel (see page 47).

(*Note.*—The life of the chemical may be extended to 10 hours if the conditions of use permit.)

20 Hours' Inspection

Air Compressor

(1) Remove and clean the oil-inlet filter and the air-intake filter.

(2) Examine the compressor and fixings for security.

Oil Reservoir

Remove and clean the oil filter at the bottom of the reservoir.

Rudder-control Unit

(1) Inspect the gyroscope rotor for free running.

(2) Oil the bearings of the rotor and gimbal rings.

(3) Decentralise the gyroscope by pulling back the centraliser cone with the fingers, to make sure that the gyroscope system and rudder valve are free.

(4) Inspect the servo-motor packing glands. They should be finger-tight, and the locking wire secure.

(5) Lubricate the leather washer of the centraliser with neat's-foot oil. For this operation remove the plug on top of the filter.

Aileron-control Unit

(1) Inspect the gyroscope rotor for free running.

(2) Oil the bearings of the rotor and gimbal rings.

(3) Decentralise the gyroscope and make sure that the gyroscope system and the valves connected with the gimbal rings all work freely.

(4) Inspect the servo-motor packing glands. They should be finger-tight.

(5) Lubricate the leather washer of the centraliser with neat's-foot oil. The air-inlet pipe must be removed for this operation.

Elevator Unit

(1) Inspect the servo-motor packing glands. They should be finger-tight.

(2) Inspect the follow-up cable and grease thoroughly with graphite grease.

Air-expansion Chamber

Remove the drain plug to release any moisture which may have collected.

40 Hours' Inspection

Rudder-control Unit

(1) Clean the relay valve and main valves with a mixture consisting of two parts of pure petrol to one part of lubricating oil, and then re-oil.

(2) Remove and clean the air filters, as follows :

(*a*) In the pipe to the spinning jets.

(*b*) In the centraliser.

(*c*) In the pipe to the relay valve.

(*d*) In the pipes leading to the course-change cylinder.

(3) Oil or grease all moving parts as required.

Aileron-control Unit

(1) Clean the relay valve, main aileron valve, precessing valve, and precessing cylinder with a mixture of pure petrol and oil.

(2) Remove and clean the air filters, as follows :

(*a*) In the pipe to the spinning jets.

(*b*) In the centraliser.

(*c*) In the pipe to the relay valve.

(3) Oil or grease all moving parts as required.

Elevator Unit

Oil or grease all moving parts as required.

Air-expansion Chamber

Remove and clean the filter in the inlet pipe.

Controls

(1) Remove and clean the air filter in the azimuth control cock.

(2) Inspect all points where the mechanism of the automatic pilot is connected to the aircraft controls for wear or shake. Re-oil or grease all fittings where necessary.

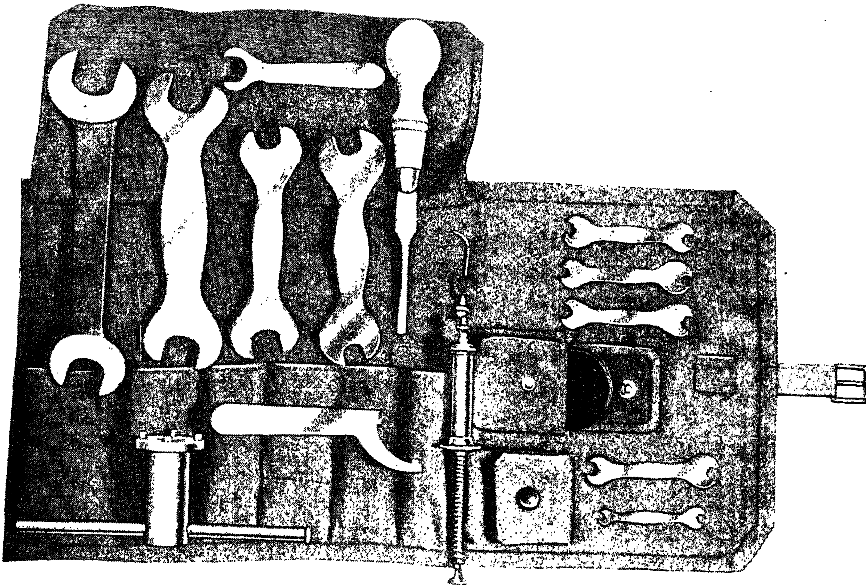


Fig. 69.—TOOL KIT

(3) Check the travel of the servo-motors of the rudder, elevator, and aileron units, and see that it is less than that of the appropriate control surfaces when the safety catches are engaged.

(*Note.*—This should also be done whenever any alteration is made to the rigging of the control surfaces.)

120 Hours' Inspection

(1) Remove all cocks and levers for stripping and cleaning. Grease all such items with anti-freezing grease on reassembly.

(2) Examine the piping for cracks or leaks.

(3) Inspect all rubber tubing for security and deterioration. Replace where necessary.

(4) Inspect all Bowden cables for wear. Re-grease thoroughly.

(5) Examine the safety-catch system thoroughly for wear, shake, and location.

(6) Make sure that the pitch and lateral control pulleys are secure on their shafts.

(7) Examine the air-compressor brake lining (if any) for wear, and lubricate the brake linkage.

(8) Remove the air compressor. Dismantle for inspection and cleaning. When reassembling it is important that the rotor blades should be reassembled in their original slots and in the same direction.

(9) Examine the automatic cut-out and quick-release units, clean the air valves, and re-oil.

(10) Examine all units for security of fixture and also all pipe connections and wiring.

(11) Remove and examine the air-intake throttle, paying particular attention to the seating and the valve face.

(12) Remove and examine the Mark IV automatic valve. Examine the valve seating.

(13) Thoroughly clean the fins of the oil cooler if fitted.

(14) Carry out a complete ground and air test of the installation when the overhaul is completed, as described on pages 103–108.

(*Note.*—It should be understood that each of the above maintenance schedules must include in addition the instructions contained in the earlier schedules in so far as they are applicable. For example, when carrying out the 40-hour inspection, the daily, 5-hour, and 20-hour instructions must be carried out in addition.)

Acknowledgment

The above details of the operation and maintenance of the Smith Automatic Pilot are reproduced by courtesy of Messrs. Smith's Aircraft Instruments Ltd. We should like to take this opportunity of expressing our indebtedness to this firm for their co-operation in enabling us to publish this information.

ELECTRICAL TEMPERATURE MEASURING INSTRUMENTS

THERE are two methods of measuring electrically the temperatures met with on aeroplanes, and the choice is determined by the actual range required. From about − 40° C. to 100° C. (maximum) the resistance thermometer can be successfully employed, but where the highest temperatures are met, say 300–350° C., it is more convenient to use the electric thermocouple method of measurement.

Resistance Thermometers

These are used for measuring the temperatures of oil, water, air, and carburettors, and are constructed to operate directly off a 12- or 24-volt battery.

The principle is that of the well-known Wheatstone bridge, where three known arms are balanced with respect to a fourth and unknown arm. Fig. 2 illustrates this.

In the case of an instrument designed for temperature measurement, three of the arms would be of a material such as manganin, whose electrical resistance does not change with temperature, whilst the fourth arm would be a coil of a material such as copper, whose resistance changes considerably with temperature. The usual galvanometer would be replaced by a pivoted instrument calibrated in degrees, so that the "out-of-balance" current in the bridge would depend on the resistance of the fourth arm and would be a measure of the temperature of that arm.

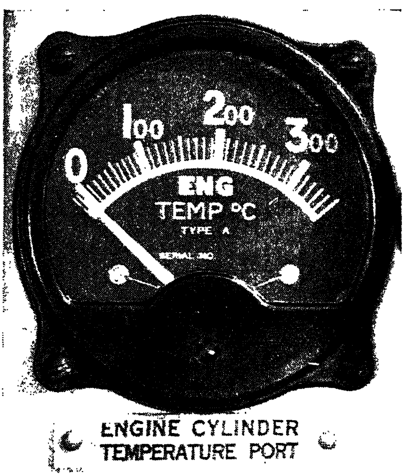


Fig. 1.—CYLINDER TEMPERATURE INDICATOR

In Actual Practice

In actual practice the three arms, A, B, and C, are contained within the indicating instrument situated on the pilot's instrument

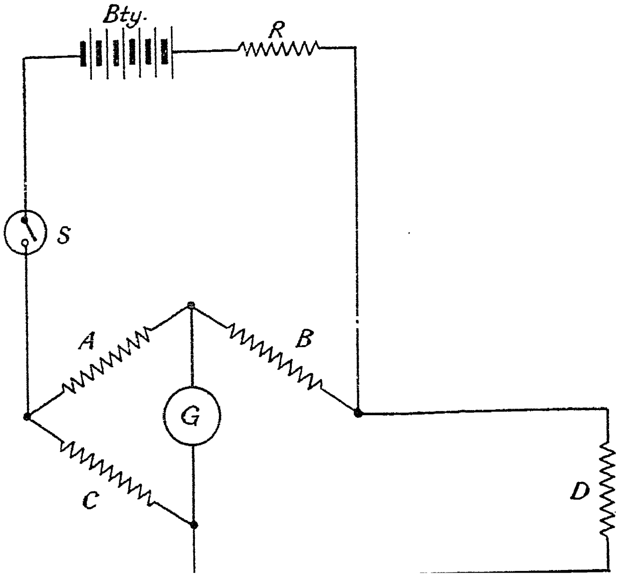


Fig. 2.—SCHEMATIC DIAGRAM OF RESISTANCE THERMOMETER

A, B, and C. Manganin spools mounted within indicator.
D. Resistance bulb.
G. Pivoted instrument replacing usual galvanometer.
R. Resistance for adjustment purposes mounted within indicator.
BTY. Battery.
S. Switch.

panel, whilst the arm D is simply a spiral mounted within a protective metal tube which is placed at the point where it is desired to measure temperature, i.e. in the oil or water tanks or in the air intakes to the engine.

Range

Ranges of resistance thermometers are decided by the ratios of the arms A, B, and C, and also by the series resistance R, and it is usual to make the indicator with a centre or set-up zero so that temperatures above or below a given point may be measured.

Cabling

The cabling of resistance thermometers is comparatively simple, as the current taken is small, but it is essential that the resistance of the cable be closer to the figure specified by the makers of the indicator, as they necessarily include the resistance of this cable in their design calculations for the arm D, or resistance bulb as it is sometimes known.

Maintenance and Faults

Resistance thermometers are comparatively free from faults, and those which do develop generally require the instrument or bulb to be returned to the makers for repair. If the indicator pointer swings hard over, either to left or right, with the battery connected and switched on and the resistance bulb in circuit, it means that one of the arms is disconnected. As to which one it is determines the direction of the swing, but in any case the instrument and the bulb should be returned to the makers, unless one

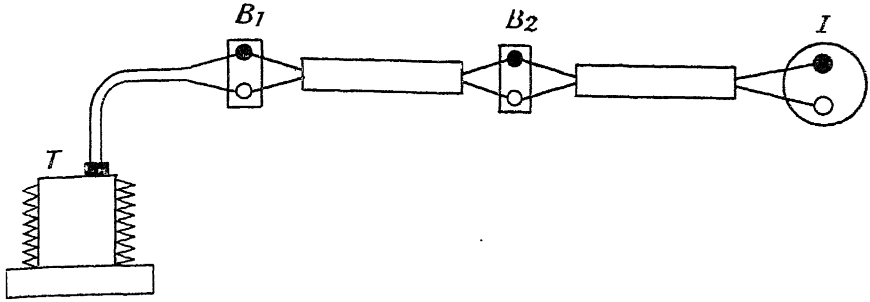


Fig. 3.—Schematic diagram for engine-cylinder temperature indicator

T. Thermocouple on engine.
B1. Terminal block on fireproof bulkhead.
B2. Terminal block at wing root.
● Constantan wire.
○ Copper wire.
I. Indicating instrument in pilot's cockpit.

or the other can be proved correct by working it in conjunction with another partner.

All indicators used in resistance thermometry are of necessity delicate, and should be handled with care, both before and during installation. It should be remembered also that, like many other instruments, they are sealed by the makers, and that to break the seals in an attempt to correct a fault will generally result in the makers disclaiming any responsibility for failure.

Engine Temperature Indicators

These are invariably of the thermocouple type, and in order to fully understand the principle of operation the essential theory of thermocouple thermometry should be mastered. A very common type is the Weston Engine Cylinder Temperature Indicator, made in the United States by the Weston Electrical Instrument Corporation and by Sangamo-Weston, Ltd., in this country.

The pointer of this instrument is moved both mechanically and electrically, and it is for this reason that an understanding of "first principles" must be obtained.

Thermocouple Theory

When any two dissimilar metals, pure or alloyed, are joined in a closed electrical circuit and one of the joints is subjected to a temperature change relative to the other, a potential is developed between the metals and a current will flow in the circuit. The magnitude of the potential will depend on the temperature difference between the junctions, whilst the current flowing will depend on the resistance of the circuit.

Fig. 3 shows a circuit composed of the metals commonly used for

engine temperature thermocouples, namely, copper and constantan, the latter being an alloy of copper and nickel. Obviously there must be two junctions in the circuit, and if we insert an indicator it must always be remembered that the reading will depend on the temperature *difference* between the temperatures at those two points.

Cold Junction Compensation

Now, in a practical case the hot junction will follow the engine temperature, but the cold junction will follow the cockpit temperature, as it is arranged to be inside the indicator, and so it would seem that measurement could not be made, as the two temperatures would move independently of each other. This is so, and cold junction compensation must be introduced in order to counteract it.

One method, not particularly suitable so far as aeroplanes are concerned, is to mount the cold junction in a "Thermos"-type flask, so that it will always be more or less at a constant temperature.

The other method, and the one which is adopted in Weston instruments for this work, is to mount a spring just above the pointer and mechanically connected to it, and made of a material such that it will curl or uncurl by exactly the same amount as the error introduced by cold junction variation.

Example

If the engine temperature was 250° C. and the cockpit temperature 20° C., the thermocouple on the engine would develop a voltage bearing some relationship to 250 — 20 = 230° C.

Then, if the cockpit temperature dropped during flight to 10° C., the voltage of the couple would bear some relationship to 250 — 10 = 240° C.

It would therefore appear that the engine had become hotter, whereas the true state of affairs would be that the cold junction had become colder. The compensating spring on a Weston indicator would curl up a little and revolve the movement, so that the pointer dropped down scale and still indicated the true engine temperature, in this case 250° C.

Now if the compensating spring is to be at the same temperature as the cold junction, the two must be near each other, and this is why the cold junction is arranged to be in the instrument casing, which means that copper and constantan wires must be brought from the thermocouple, back to the instrument, as the cold junction is at the point where a change of material of which the cable is made takes place.

For this reason, the connecting terminals of the indicator are made of brass (electrically similar to copper for thermocouple work) and constantan.

The indicator itself is a sensitive millivoltmeter, and has a full-scale deflection for about 17·5 millivolts, which corresponds to a temperature of about 350° C., using a copper-constantan couple.

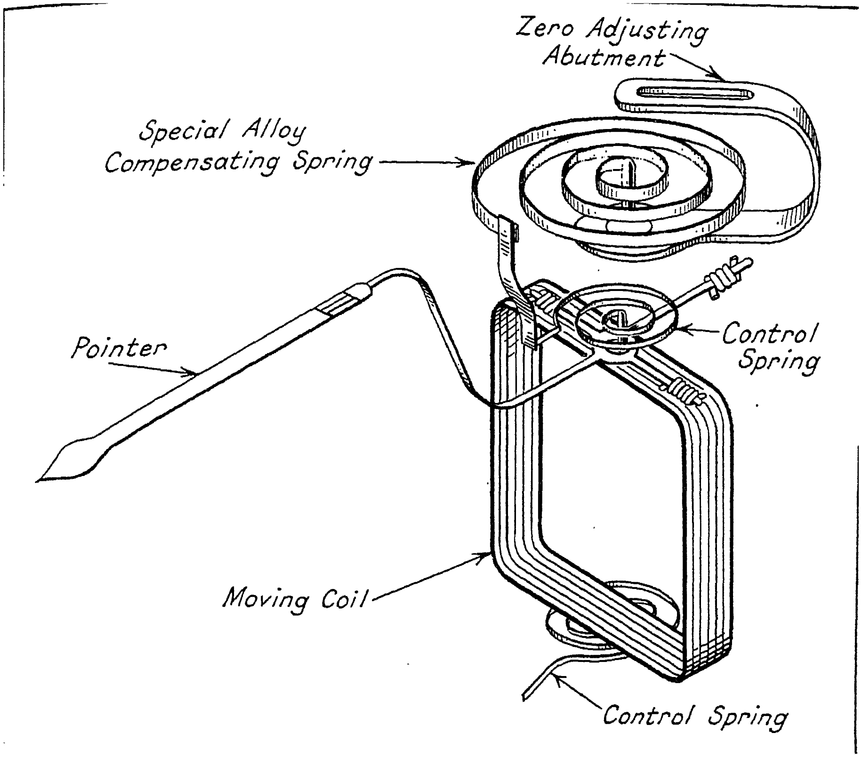


Fig. 4.—THE WESTON ENGINE-CYLINDER TEMPERATURE INDICATOR

Showing the moving element of the indicator. This is mounted in a suitable bracket within the poles of a permanent magnet in the usual manner.

Pivots are mounted in the centres of the two control springs. The compensating spring is attached to the zero abutment at its inner end.

The control springs are very weak but the compensating spring is considerably thicker and more rigid and forms a firm unit in conjunction with the zero abutment. It can only move bodily with the zero adjuster, or spirally by being subjected to a temperature change.

Theory has been dealt with at some length, but it is necessary in order to appreciate the reason for using copper-constantan leads between the thermocouple and the instrument, and also why the pointer moves with room temperature variation, even when the engine is not running. This is so because the compensating spring moves the pointer mechanically and not electrically. It is made of special thermostatic metal (see Fig. 4).

Installation and Maintenance

The thermocouple must be clamped under a suitable part of the engine, that is, on a cylinder. If it is a ring type it can be clamped under a sparking plug, or if it is of the shoe type under a convenient bolt.

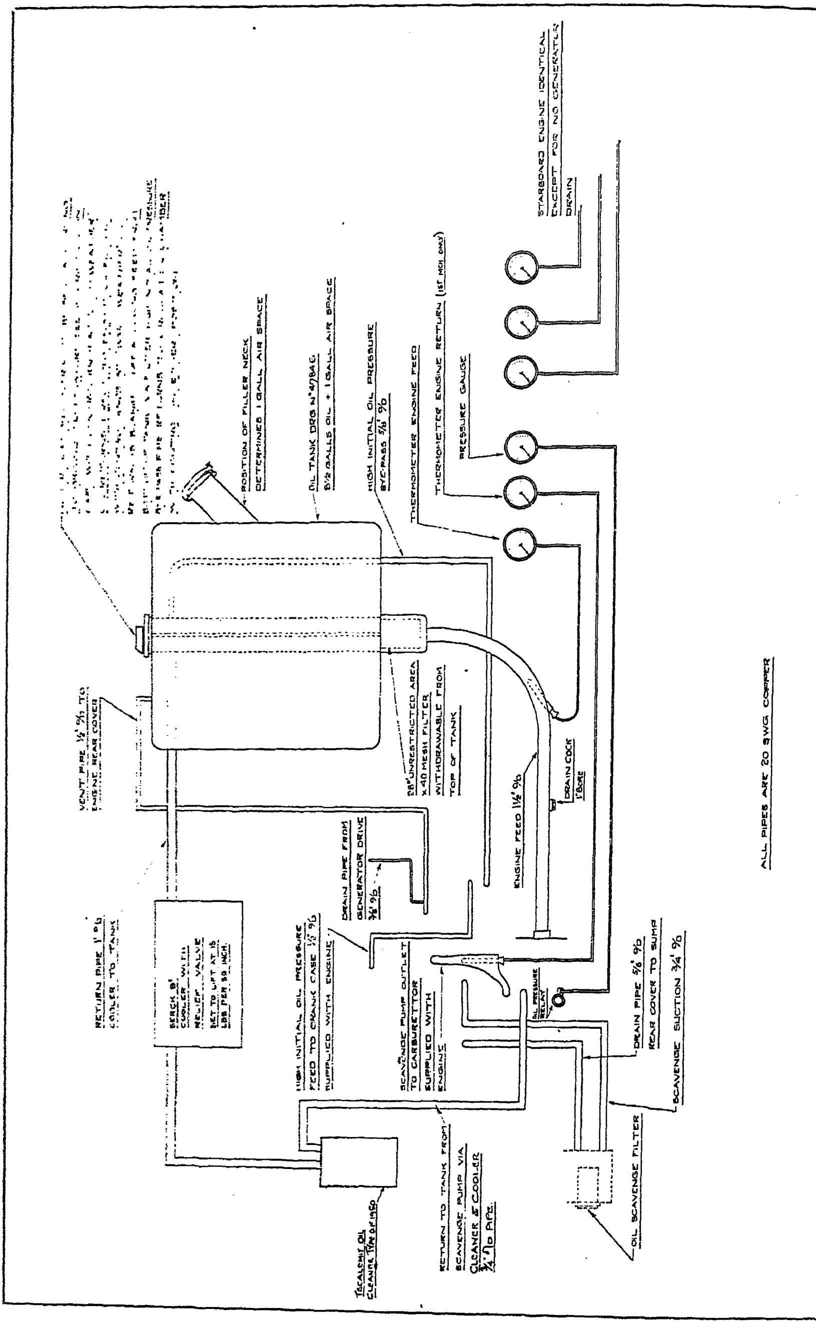


Fig. 5.—A TYPICAL OIL SYSTEM, SHOWING POSITION OF THE OIL-TEMPERATURE INDICATORS. (*By courtesy of the Bristol*

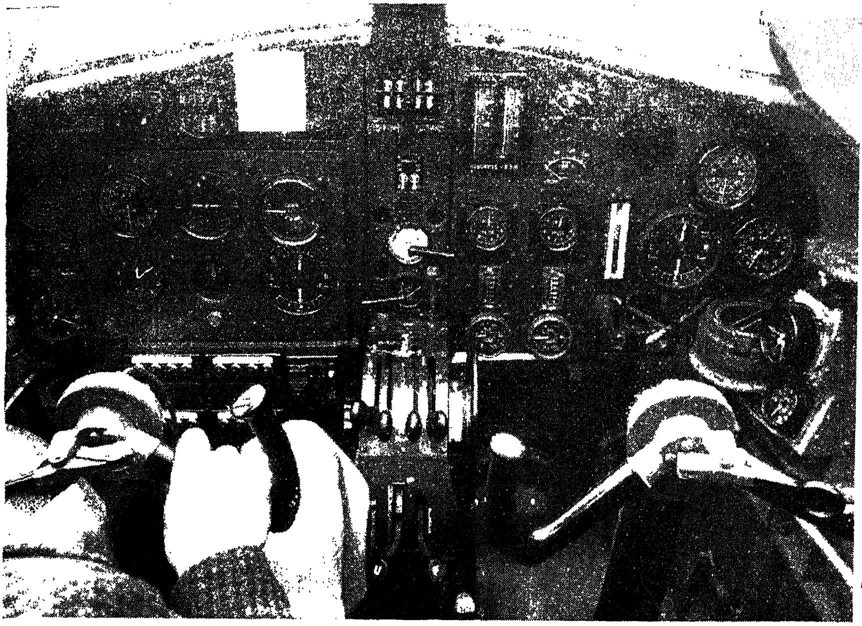


Fig. 6.—INSTRUMENT PANEL ON AIRSPEED "OXFORD"
Showing electrical engine-temperature indicators at top right.

Leads supplied by the makers must be used, and they must not be cut or added to in any way, the standard lengths being 10 ft., 20 ft., 30 ft., increasing by 10 up to 80 ft. Generally the run on a large aeroplane is divided into three parts :

(1) Engine to fireproof bulkhead.
(2) Fireproof bulkhead to wing root.
(3) Wing root to instrument in pilot's cockpit.

With (1) the standard length at present is 6 ft. for all types, its resistance being 0·25 ohm. The resistance of the whole circuit (thermocouple on engine to instrument) is standardised at 2 ohms. Therefore, in the case quoted above, there would be 1·75 ohms left for (2) and (3), that is, 0·875 ohm each. This is most important, and when ordering, the resistance per section is 1·75 divided by the number of sections, or alternatively to tell the makers, " Fireproof bulkhead to instrument, divided into 2, 3, or more sections," as the case may be.

Junction Connections

With regard to junction connections, it has been found in actual practice that the accuracy of the readings is not altered when the constantan lead is joined with brass terminals.

Occasional Checks

Occasional checks should be made to see that, with the couple disconnected or the switch in the OFF position, where one is fitted, the pointer indicates room temperature as measured by an ordinary thermometer hung near it. If it does not, adjustment should be made by means of the zero adjuster on the front of the instrument. Switch contacts should be kept in a clean and " sweet "-moving condition, as the total voltage in the circuit is only 0·017 volt and dirty contacts will invariably cause errors in reading, the temperature indicated being lower than the true temperature. Finally, it should be remembered that the instrument is delicate and should never be handled roughly or dropped, and when removed from the aeroplane the terminals should be short-circuited by means of a piece of copper wire in order to damp the movement and so prevent damage.

INSTRUMENTS

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